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EMULSIFIED FUEL SYSTEM DESIGN STUDY

By

Richard H. Hollinger

October 1969

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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FRANKLIN INSTITUTE RESEARCH LABORATORIES

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This report contains the results of investigations of emulsified JP-4 fuel systems conducted by Franklin Institute Research Laboratories, Philadelphia, Pennsylvania, under the terms of Contract DAAJ02-68-C-0061.

The object of this program was to determine the design features and techniques that would permit the fuel system to deliver emulsified JP-4 fuel from the fuel tanks of Army aircraft to the engine in a dependable manner.

The program objectives were met, and the recommended fuel system design is presented and discussed in detail herein.

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EMULSIFIED FUEL SYSTEM DESIGN STUDY

Final Report

by

Richard H. Hollinger

Prepared by

Franklin Institute Research Laboratories
Philadelphia, Pennsylvania

for

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

The object of this program was to determine the design features and techniques which would permit the fuel system to deliver emulsified JP-4 fuel from the fuel tanks of United States Army aircraft to the engine in a dependable manner. The study was carried out in a series of experimental investigations covering emulsion behavior, fuel lines and fittings, fuel boost pumps, fuel filtering and decontamination, fuel quantity measurement, fuel tank design, and fueling techniques. The studies indicated that current systems are usable providing that fuel lines are made of, or lined with, polytetrafluoroethylene or polycarbonate and that line inside diameters are not less than 1.0 inch. Fuel tanks should have bottoms which are angled 30 degrees, and the tank interior should be lined either with polytetrafluoroethylene or with polyethylene. Filtration of the emulsified fuel is limited to approximately 115 microns. Centrifugal fuel boost pumps perform with reduced efficiency, but some are usable. Inlets for the pumps should be modified to reduce fuel hang-up, and provision should be made to eliminate emulsion breakage by the pumps during periods of low flow demand. A capacitance gauge with insulated probe was found to be satisfactory for measurement of fuel quantity. Tank fueling operations will require low shear pumps, and the fuel should enter the tanks from the bottom.

The major limitations, for which further investigation is recommended, are the breakage of emulsion by the pumps during low flow demand, which leads to pressure and flow pulsations when higher flow demands are restored, and the limit of 115 microns for fuel filtration, which is felt to be five times too high.

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INTRODUCTION

Emulsified JP-4 fuels have characteristics which reduce the threat of fire from ballistic causes and minimize the danger of post-crash fire in otherwise survivable aircraft accidents. The same properties, however, make it more difficult to pump the fuel from the tanks to the engine-mounted fuel pump. The high apparent viscosity and the yield value for such emulsions made advisable a design study of the low pressure fuel boost system. The objective of the study was to determine what the problem areas were and either to recommend design changes to eliminate them or to note the areas in which further work will be required.

This report describes the study, which was divided into seven areas of investigation. Each investigation is described in a separate section, and an eighth section is used to describe the entire fuel boost system.

EMULSION BEHAVIOR

VISCOMETER TESTS

The three test emulsions were checked by means of a rotational viscometer to determine the shearing stress as a function of rate of strain. Preliminary tests were carried out with Emulsion B and the results are shown in Figure 1. The emulsion was tested in the relaxed or unworked state and again after mechanical working using a mixer. The shear stress at different strain rates for the worked emulsion was approximately double that of the relaxed emulsion. The increase in shearing stress was so large that air entrainment was suspected, and the tests were repeated with the emulsion being worked in the viscometer cup three times at a strain rate of 25 reciprocal seconds. The emulsion was checked in the unworked state, the worked state, and after relaxing for a period of 2 hours Figure 2 shows the results of the test. Working in the cup did not produce as much increase in shear stress as did the mechanical working, and only a slight decrease was noted in shear stress after the relaxation period. The tests were repeated using Emulsions A and C but without testing after relaxation. The test results are shown in Figures 3 and 4. Emulsions A and C show lower yield values than Emulsion B,and little change is evident between the worked and unworked states.

VISCOMETER AS AN ADHESION TESTER

In the tests with the rotational viscometer, the yield values obtained for Emulsions A and B in the relaxed state were approximately half the values obtained by penetrometer readings but still showed essentially the same percentage difference between the yield values of the two emulsions. Emulsion A,which ordinarily gave a yield value by penetrometer in the region of 600 dynes/cm^2,gave a yield value of 270 dynes/cm^2 by rotational viscometer. Emulsion B,with a normal penetrometer yield value of 1200 dynes/cm^2,showed a yield value of 620 dynes/cm^2 by rotational viscometer. Emulsion C,which by penetrometer gave yield values of about 600 dynes/cm^2, similar to Emulsion A, should have given viscometer yield values of about 270 dynes/cm^2. The yield value obtained for Emulsion C was only 30 dynes/cm^2, and close observation showed that the emulsion was not adhering to the copper viscometer cup but was adhering to the stainless steel viscometer bob.

Viscosity as determined by the rotational viscometer depends on the adhesion of the test material to the cup and bob being stronger than the shearing forces developed in the material in the annulus between the rotating bob and the fixed cup. Decreasing the adhesion would show lower viscosities or would give higher strain rates at constant shearing stress. Thus, if the bob were coated with a material with which emulsion adhesion was to be determined and a viscosity were established at a fixed shearing stress, a comparison of viscosities obtained for different coating materials should show a ranking of adhesion. Subsequent tests proved this to be the case,and the method was used to determine the emulsion adhesion properties of different tank-lining materials.

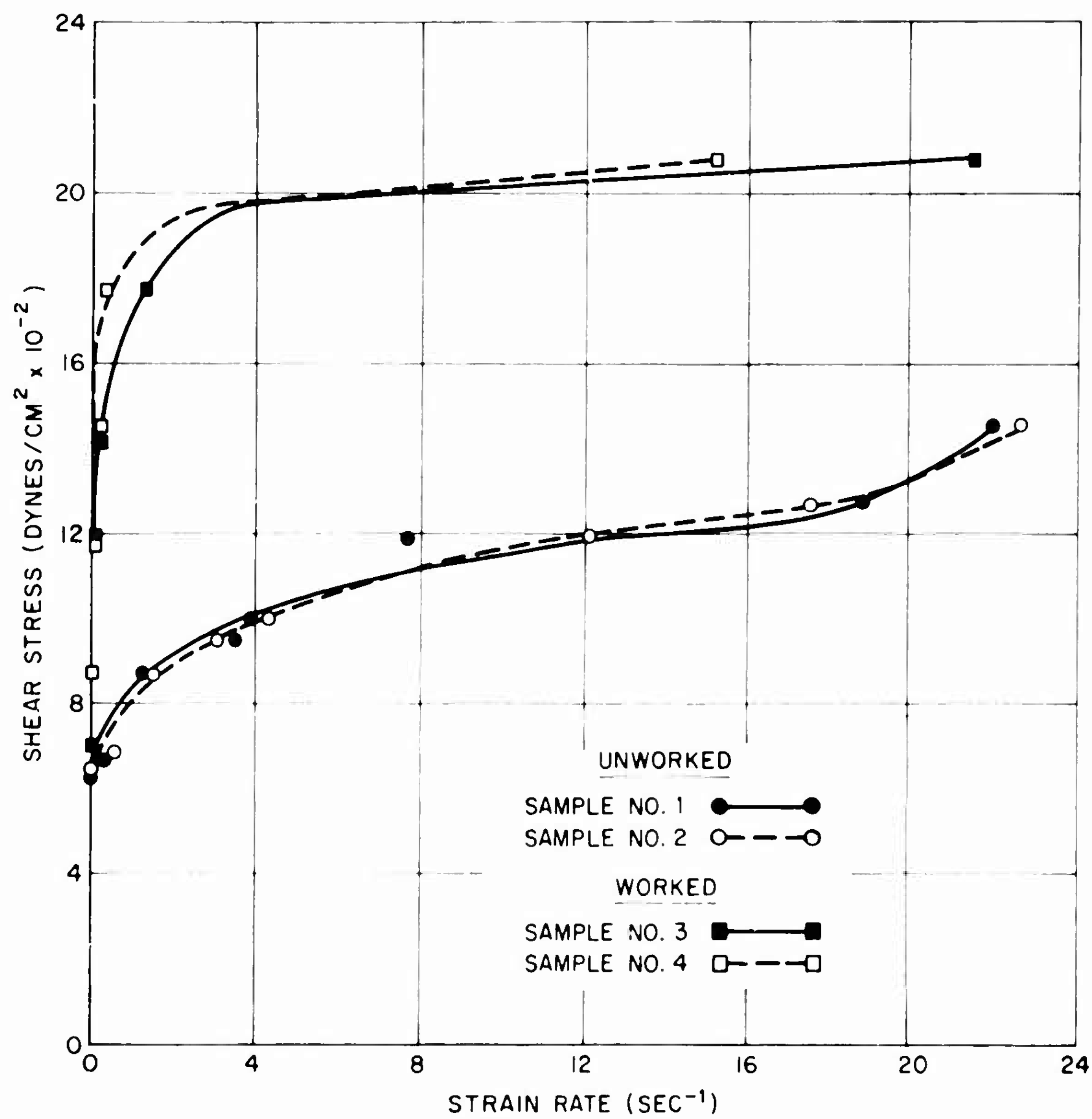

Figure 1. Emulsion B, Shearing Stress vs Strain Rate.

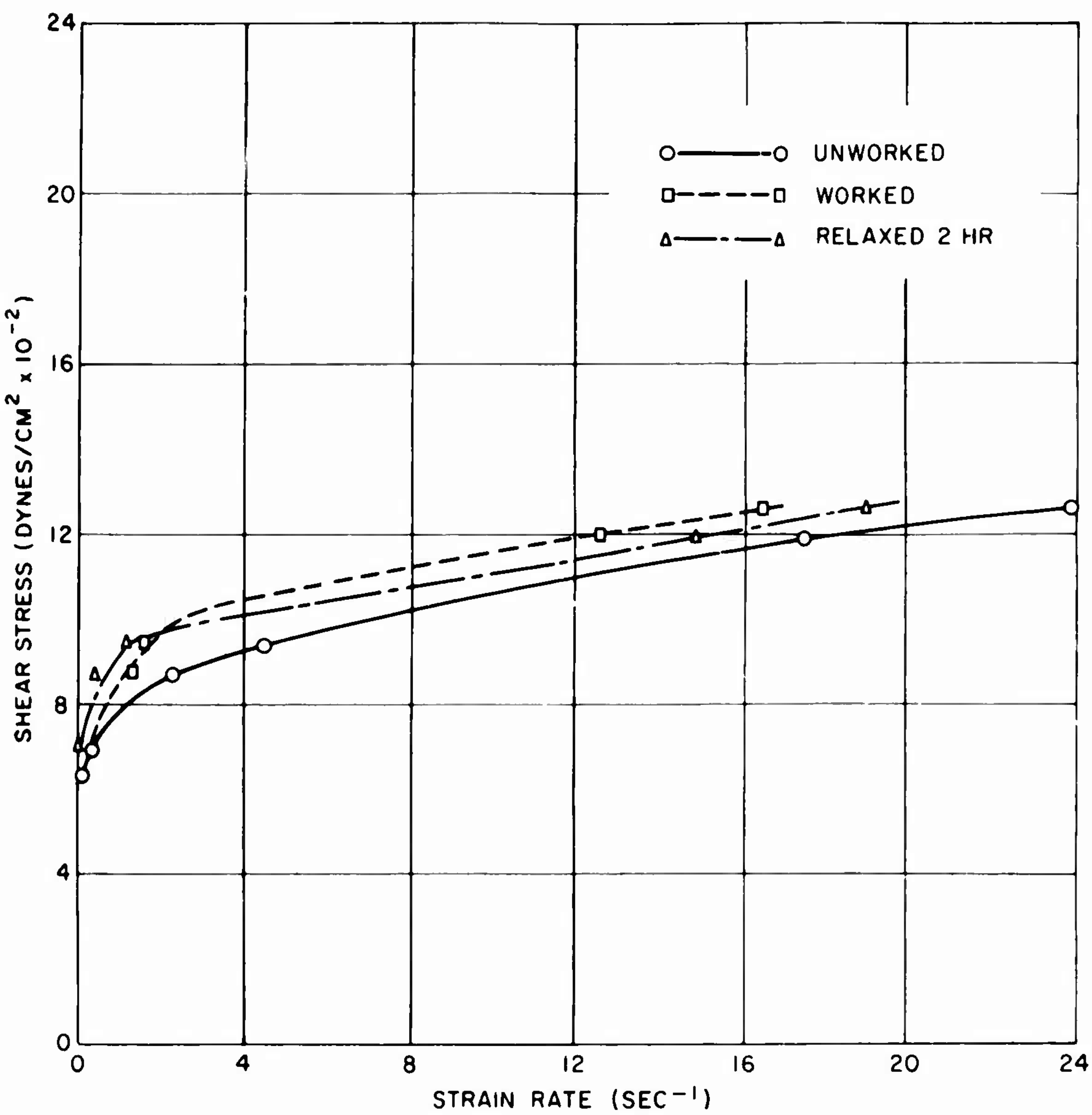

Figure 2. Emulsion B, Shearing Stress vs Strain Rate.

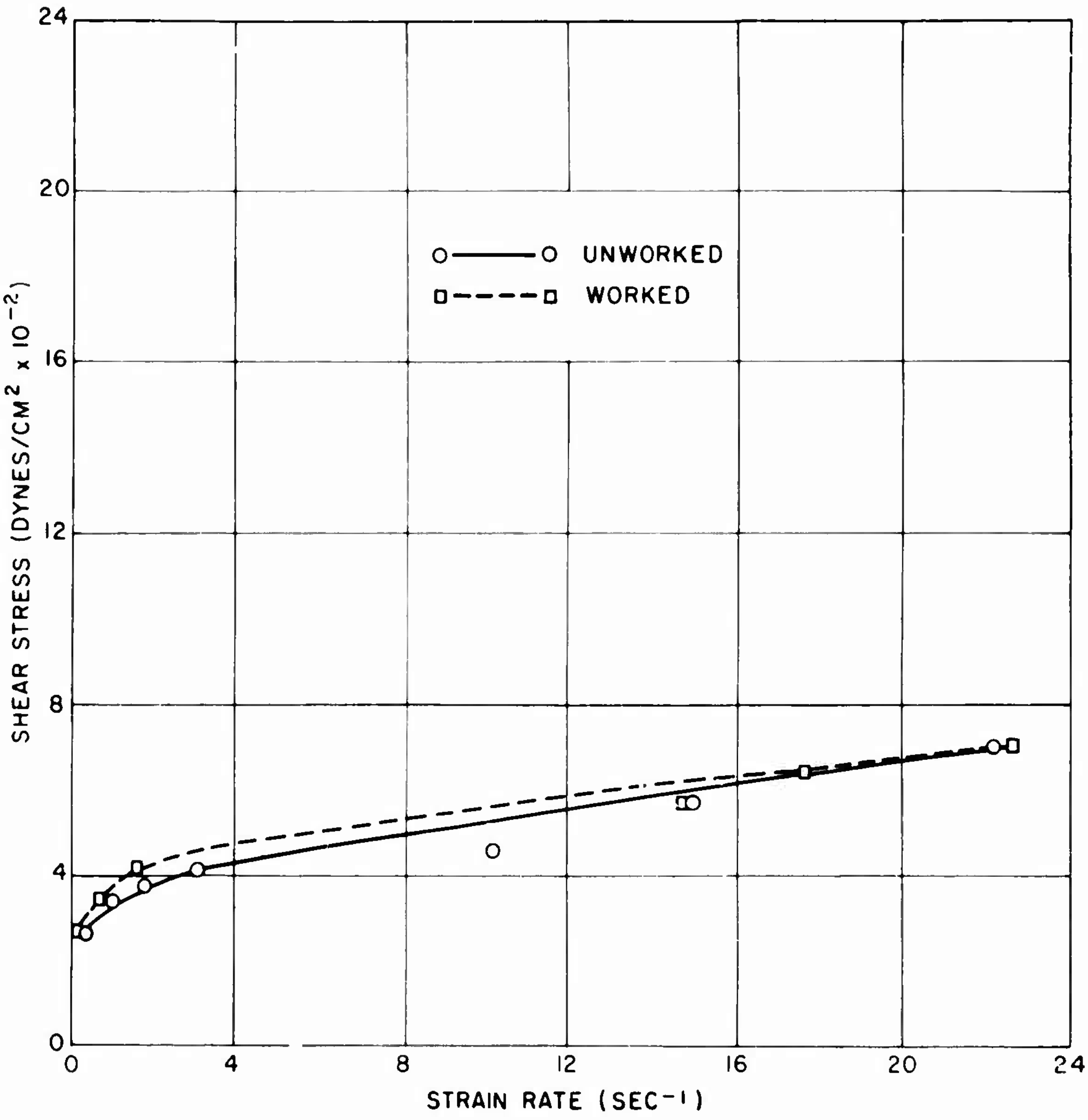

Figure 3. Emulsion A, Shearing Stress vs Strain Rate.

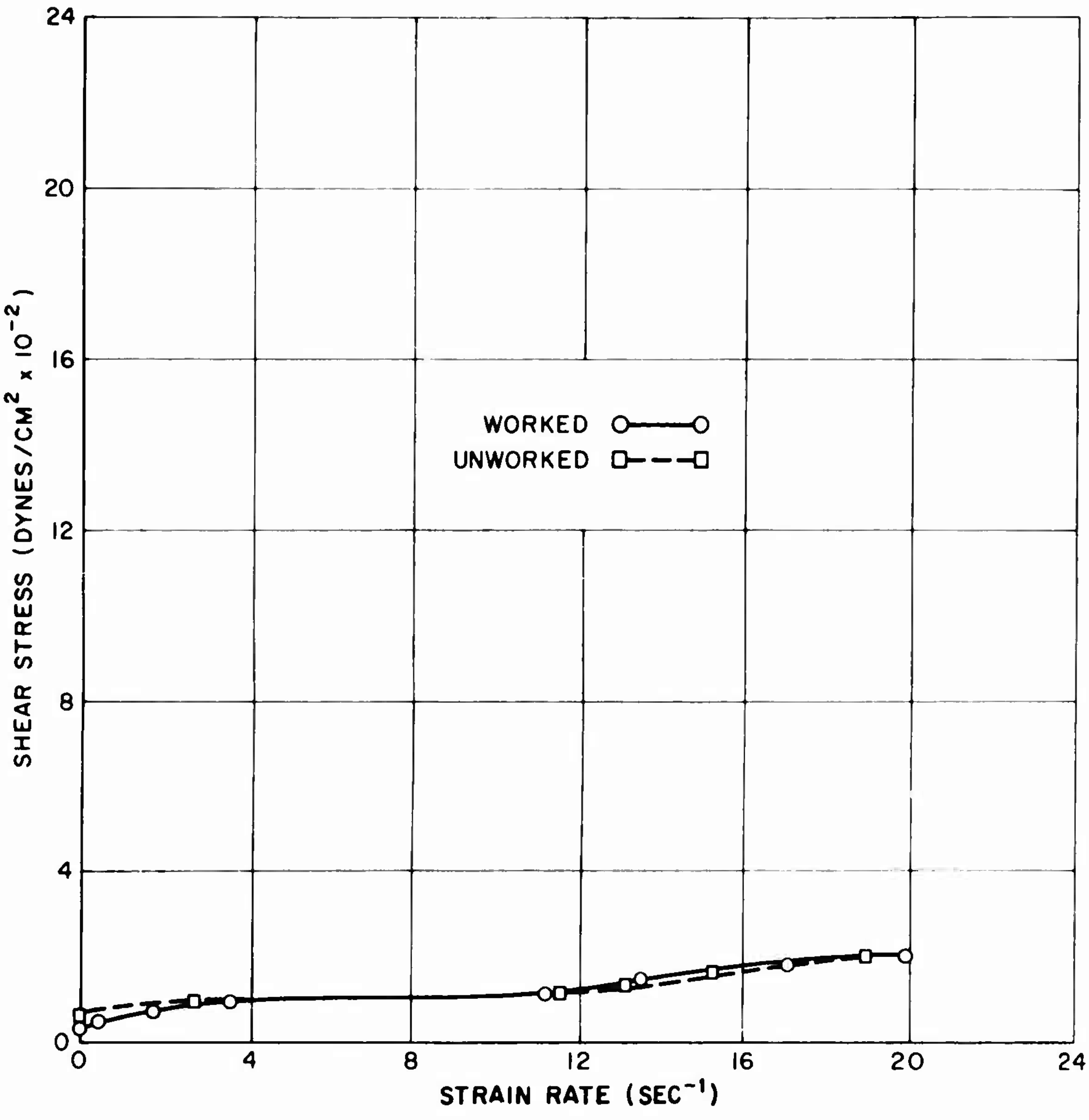

Figure 4. Emulsion C, Shearing Stress vs Strain Rate.

Since adhesion of the emulsion to the surfaces in the test apparatus is a key to viscosity and yield value determinations by most methods, and since the adhesion of a given emulsion can vary depending on the surface material and the amount of emulsion breaking, the most satisfactory method for determining emulsion yield values is the penetrometer method.

YIELD VALUES DURING TESTS

During tests of tanks, tubing, pumps, filters, and fuel quantity measurements, the emulsions were used on a single-pass basis. The yield value for the emulsions at the start of tests covered the following ranges:

Emulsion A	500- 700 dynes/cm^2
Emulsion B	1100-1250 dynes/cm^2
Emulsion C	600- 700 dynes/cm^2

After tests involving shearing of the emulsions, yield values in the following ranges were found.

Emulsion A	900-1300 dynes/cm^2
Emulsion B	1600-2500 dynes/cm^2
Emulsion C	900-1300 dynes/cm^2

Changes in emulsion yield values which occurred during the tests did not have an apparent effect on the test results. Since the single pass technique was used and the emulsion then was discarded, the tests were run with essentially the same initial yield value for the emulsion concerned. Later in the program, tests were intentionally made at different yield values with Emulsion A.

While yield value changes did not show significant effects during tests, the factor which did give difficulty was partial breaking of the emulsions. Partial emulsion breakage occurred after periods of exposure to high shearing forces such as those encountered when the emulsions were being pumped by a boost pump against a partially closed or closed valve in order to decrease flow and increase pressure. Under these conditions, when the valve was reopened, a period of pulsing flow and pressure occurred. The emulsion which was sheared by the pump and broken flowed very readily at low line pressure drop, but the emulsion following it through the pump into the lines would not flow as readily. This resulted in decreased flow and an increase in pressure until sufficient pressure was available to move the unbroken emulsion. During the low flow period, more emulsion was broken by the pump so that, when the unbroken emulsion began to flow, the broken material entered the lines and the cycle was repeated until uniform flow was reestablished. The period for reestablishment of normal flow ranged between 45 and 60 seconds. In some cases, flow was observed to stop completely and begin again very suddenly as a plug of emulsion was expelled from the lines. This condition is serious in that pulsing flow to the engine-driven pump could bring about cavitation and fuel starvation when high flows are required after a low flow demand period.

EMULSION A WITH INCREASED YIELD

A series of tests using Emulsion A in a relaxed state and increased yield states was undertaken to determine the effect on flow through tubes, flow through fittings and filters, and pump behavior. Depending on the degree of mechanical work, the yield value could be increased by steps up to a maximum yield of 1700 to 1800 dynes/cm^2,at which point emulsion breaking was evident. For emulsion with yield values in this range, pump priming was difficult, and, even if flow began, the pumps lost their prime and began to cavitate. The actual yield values obtained for the tests are shown together with the test results in the appropriate sections of this report.

EMULSION STRUCTURE MODEL

In order to explain the behavior of the test emulsions,starting from the relaxed state, increasing the yield values with mechanical working, and ending, ultimately, with emulsion breaking, a theoretical model of the emulsion structure was devised. In the relaxed state, the droplets of the JP-4 internal phase are of larger size,thus presenting a lower surface area. Not all of the emulsifying agent is required to cover this surface area, and micelle formation of the excess agent occurs in the continuous phase. Also, the distance between JP-4 droplets would be greater since the reduced surface area requires less of the exterior phase at the interface. The droplets would have higher mobility in this state, which is another way of saying that the yield value would be lower. With mechanical working, the JP-4 droplets are decreased in size with a resultant increase in surface area. Emulsifying agent leaves the micelle formations and covers the increased surface area, while the droplet separation becomes less because more exterior phase must cover the interfaces. In this state, the yield value of the emulsion would increase because the thickness of the exterior phase separating the droplets is reduced. At some point, as the JP-4 droplets are further reduced in size, the available emulsifying agent and exterior phase can no longer satisfy the demands of the increased surface area, and coalescence of the JP-4 droplets begins,thus signifying emulsion breaking. If mechanical working is stopped short of emulsion breaking, the JP-4 droplets undergo a more gradual coalescence until a stable size is reached,with the excess emulsifying agent again forming micelles, and the increased thickness of exterior phase gives the emulsion the properties, once more, of the relaxed state.

FUEL LINES AND FITTINGS

MATERIALS

The high apparent viscosity of emulsified JP-4 was expected to cause excessive pressure drop through the fuel lines currently in use, and the use of various friction-reducing lining materials for tubing was investigated. The materials selected for test were:

1. Polytetrafluoroethylene
2. Polyethylene (Low Density)
3. Polycarbonate
4. Polyvinyl Chloride
5. Nylon
6. Stainless Steel (Reference Material)

Polyvinyl was dropped from the list after several tests since hardening and cracking were evident after contact with the emulsions.

The tube inside diameters selected for the tests were 0.250 inch, 0.375 inch, 0.625 inch, and, later, 1.0 inch and 1.25 inches. The tube length in all tests was 32.5 inches.

METHOD

The tubing tests were carried out using the apparatus shown schematically in Figure 5. The test emulsion was pumped into the feed tank from the drum. The feed tank was then pressurized with nitrogen, and the emulsion was forced through the 32.5 inch-long section of tubing under test and into the receiving tank. The tubing test section is shown in Figure 6. The pressure transducers located in the housings at each end of the tube section had their electrical outputs bridged, and the bridged voltage was displayed on the digital millivoltmeter. The voltage displayed was translated into pressure differential from a calibration chart. The receiving tank rested on a strain gauge load cell with a 200-pound capacity. The output from the load cell was used as the Y input for an X-Y recorder having a time base for the X axis, and, from the resulting line slope, the emulsion flow rate in pounds per hour was calculated. A typical family of recordings is shown in Figure 7. Emulsion yield values were measured by penetrometer before and after each test.

TEST RESULTS, 0.250-, 0.375-, and 0.625-INCH-INSIDE-DIAMETER TUBING

Tests with .250-inch-inside-diameter tubing gave values in excess of 8 psi pressure differential across the 32.5-inch-long test section at 100 pounds per hour flow for all three emulsions and all tubing materials. This pressure differential is far in excess of anything usable.

The results of tests with .375- and .625-inch-inside-diameter tubing are shown in Figures 8, 9, and 10 for Emulsions A, B, and C respectively.

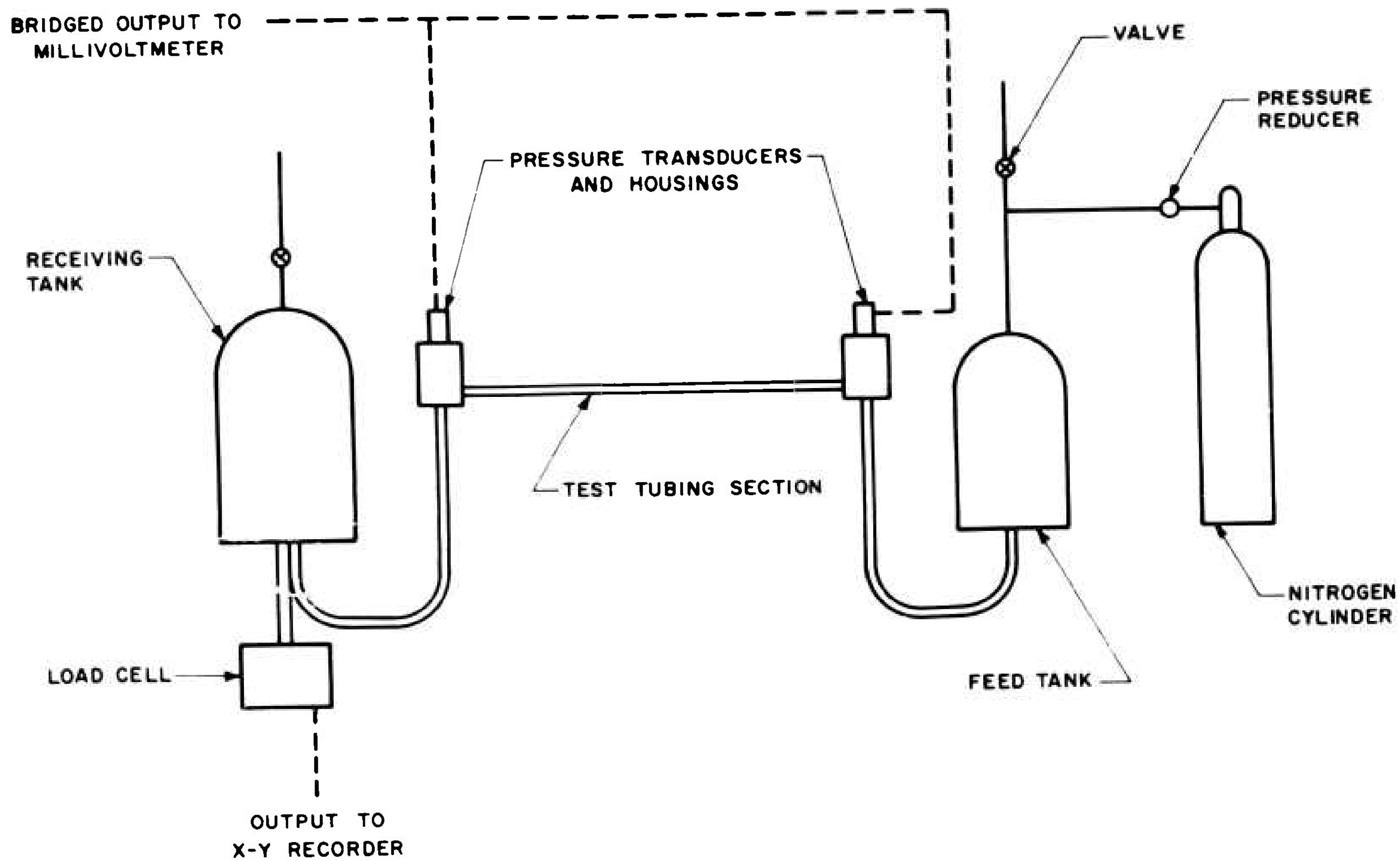

Figure 5. Schematic Drawing for Tube-Lining Materials Test Apparatus.

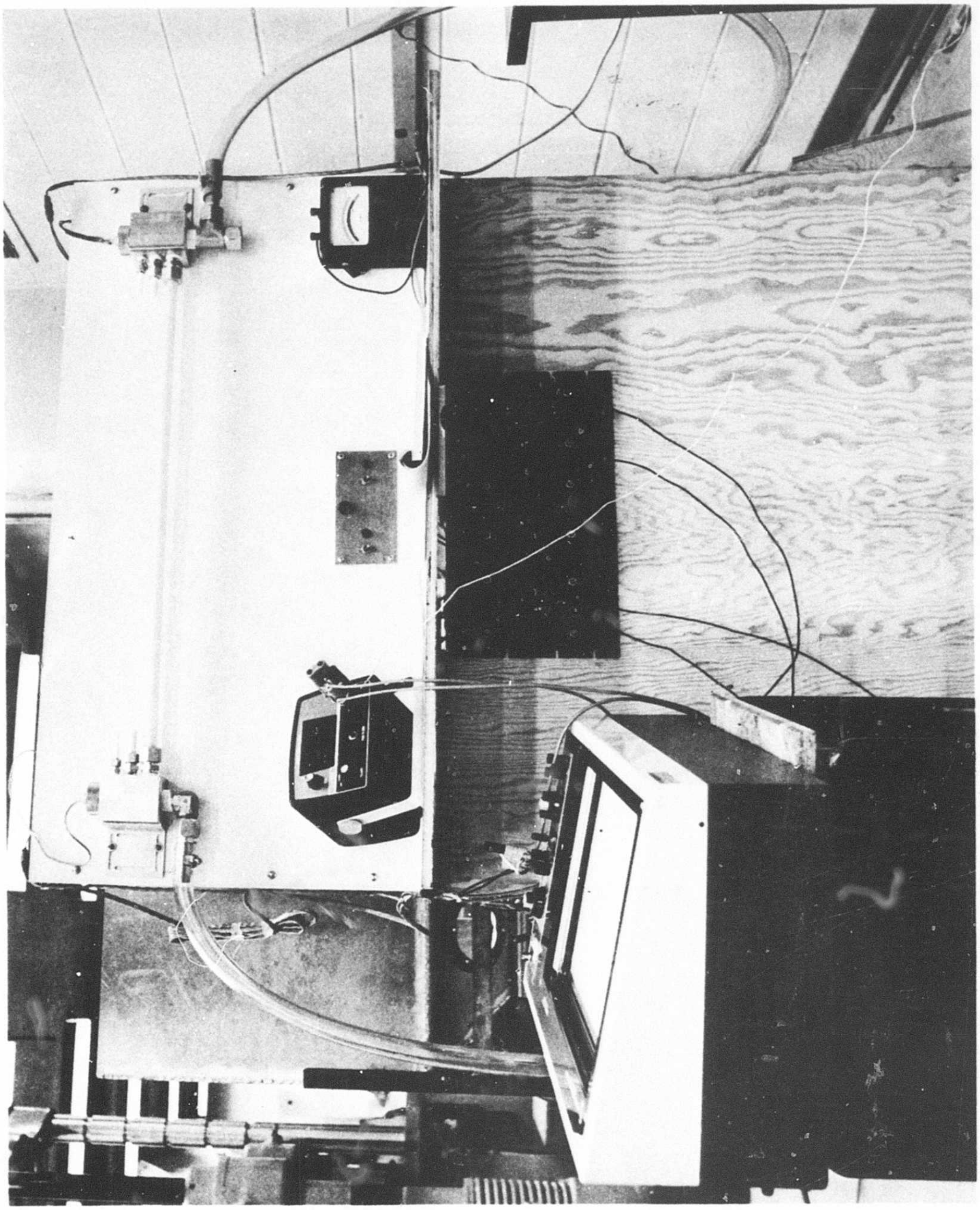

Figure 6. Tubing Test Section.

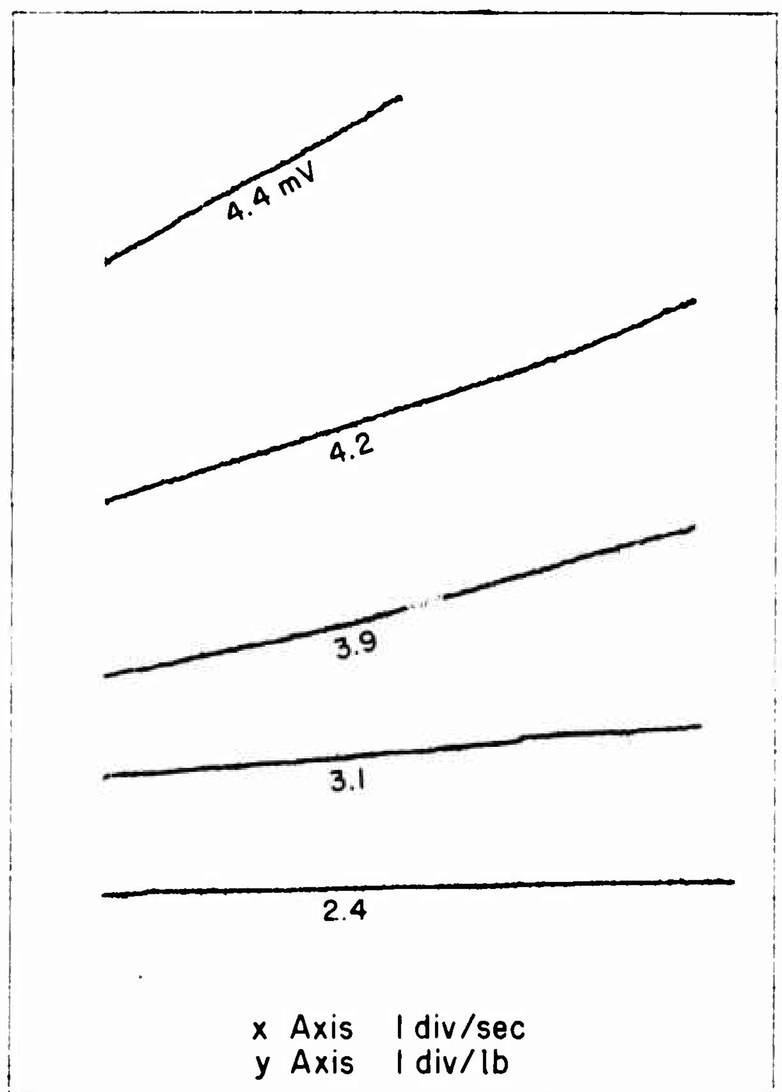

Figure 7. Family of Recordings.

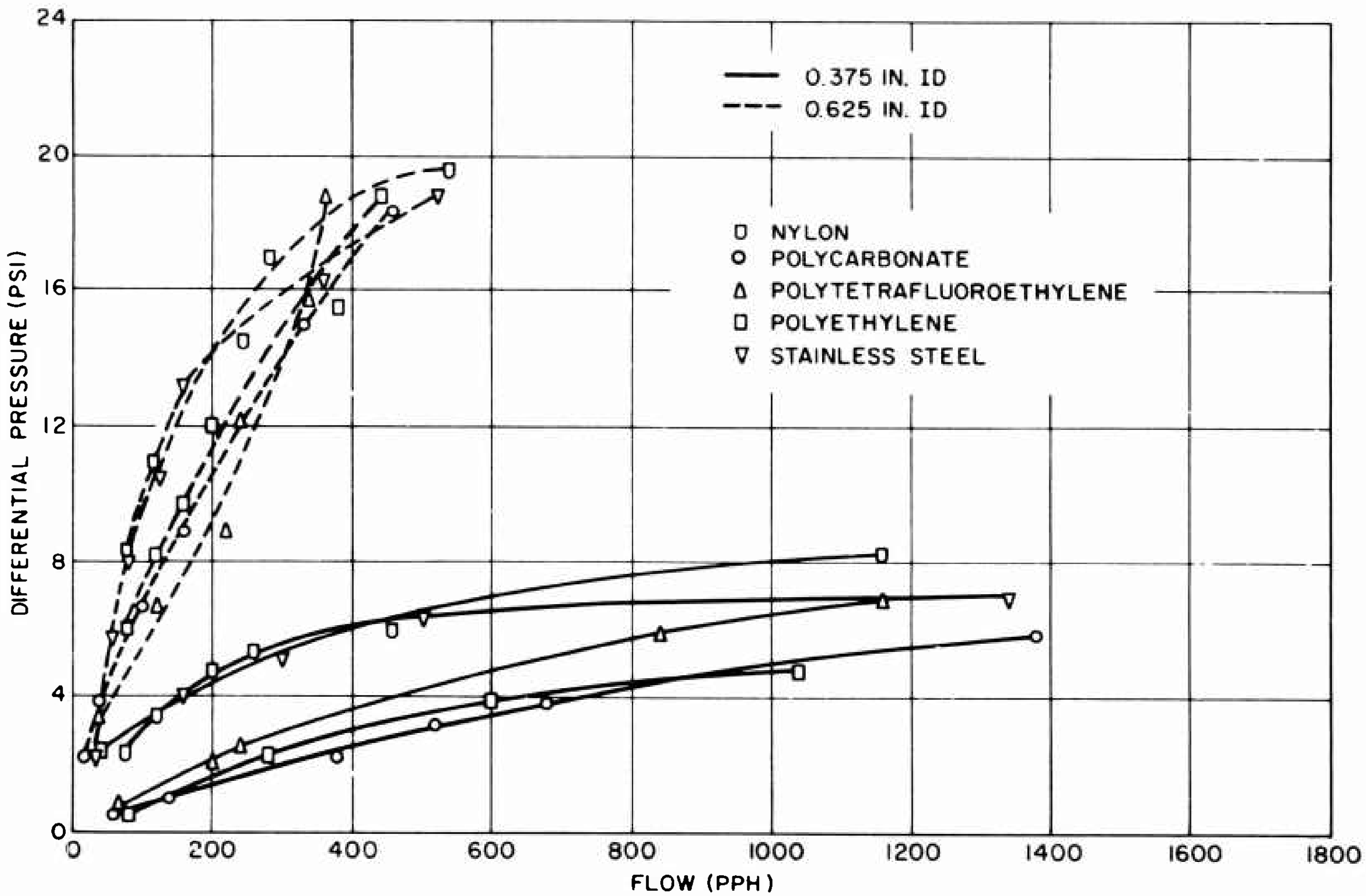

Figure 8. Flow vs Differential Pressure, Tubing Materials With Emulsion A.

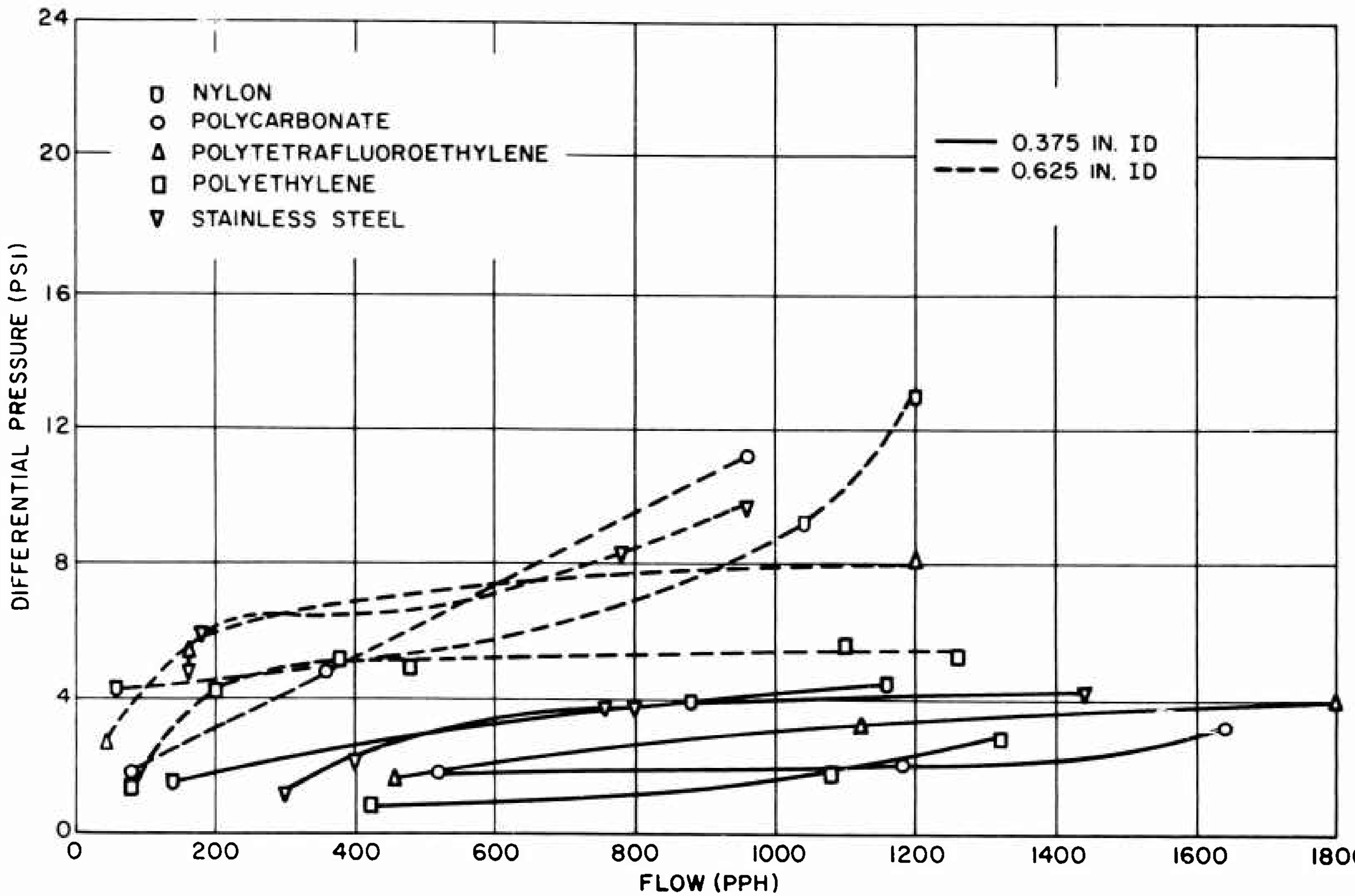

Figure 9. Flow vs Differential Pressure, Tubing Materials With Emulsion B.

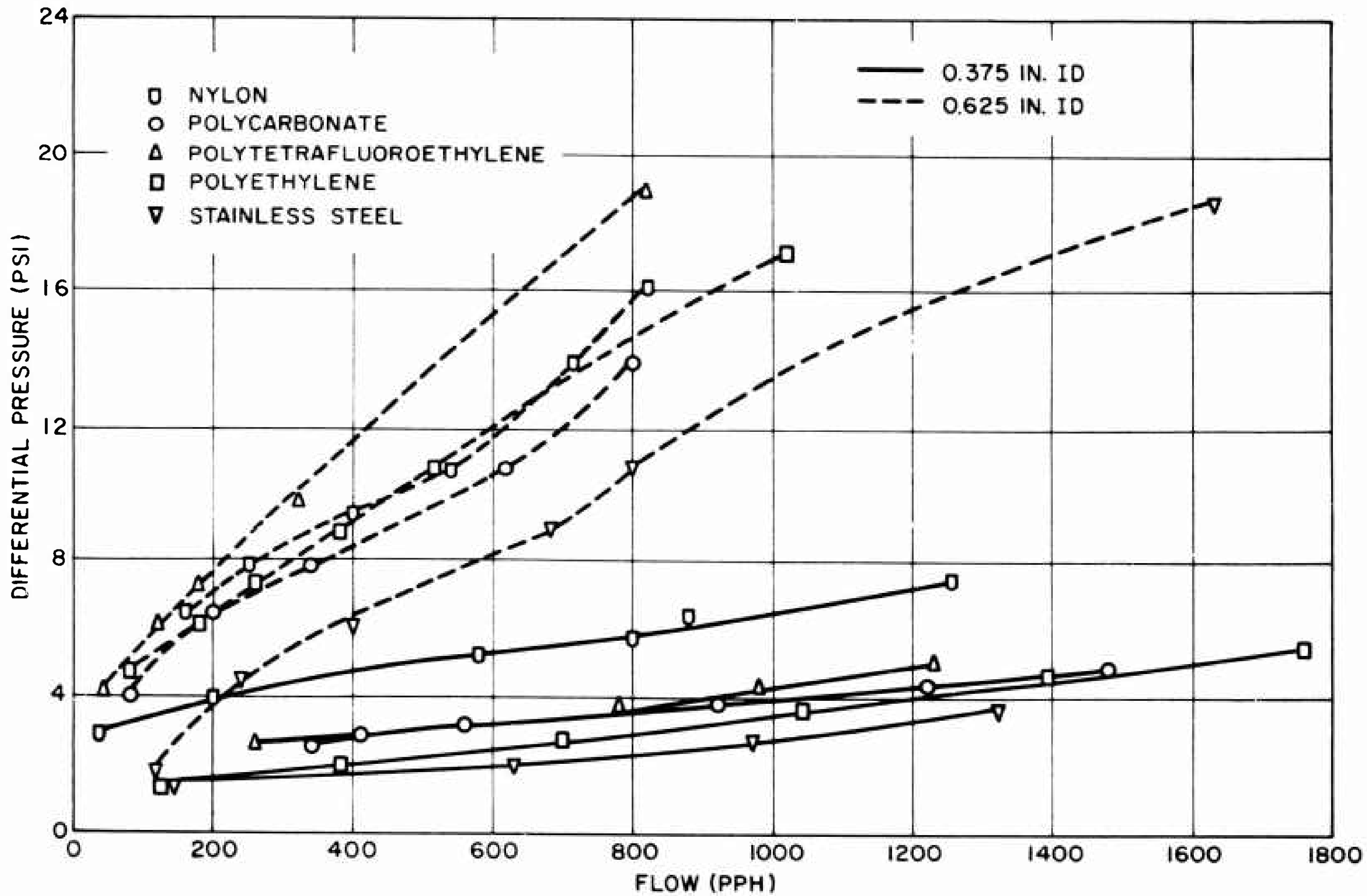

Figure 10. Flow vs Differential Pressure, Tubing Materials With Emulsion C.

The values for the pressure differential for .375-inch-inside-diameter tubing are excessive in all cases, but those for .625-inch-inside-diameter tubing are closer to usable values, and differentiation between tube materials can be made. For Emulsions A and B, nylon and stainless steel give the highest differential pressure of the tubing materials while polyethylene and polycarbonate give the lowest. In the case of Emulsion C, stainless steel is the best tubing material, although polyethylene is nearly as good. Nylon, again, gives the highest pressure drop. The behavior of Emulsion C with stainless steel may be explained if the emulsifying agent does not preferentially wet stainless steel. The adhesion of the emulsion to the stainless steel would be low, and flow would be enhanced. Some tendency of the low-density polyethylene to swell during contact with the emulsions was noted. Use of high-density polyethylene would minimize this condition.

TEST RESULTS, 1.0- AND 1.25-INCH-INSIDE-DIAMETER TUBING

Emulsion A in the relaxed and increased yield state was selected for further tests with 1.0-, and 1.25-inch-inside-diameter tubing of polyethylene, polytetrafluoroethylene, and polycarbonate. The results of these tests are shown in Figures 11 and 12. Generally, polytetrafluoroethylene gives the lowest pressure differential, followed by polycarbonate. With the larger diameter tubing, shear rate is lower and the polytetraflurorethylene, which gives the best result as a tank liner, where low shear rate is normal, gives the best results. The increased yield emulsion exhibits better flow characteristics than the emulsion in the relaxed state. In the relaxed state, adhesion is apparently greater, while in the thickened state an approach to true plug flow on a layer of lubricating liquid is probable.

TEST RESULTS, FITTINGS

Two types of fittings commonly used in fuel boost systems were tested with Emulsion A in the relaxed state and with increased yield. The fittings used were steel 90° elbows and bulkhead fittings for 1.0-inch-outside-diameter tubing. The fittings were tested with and without polyethylene linings to determine the effect on pressure differential across the fitting. The results are shown in Figures 13 and 14. With regard to the bulkhead fitting, there is an advantage to an internal lining in the case of the relaxed state emulsion. This is not obvious in the case of the thickened emulsion. The thickened emulsion has better flow characteristics through an uncoated fitting than does the relaxed state emulsion, but the opposite is the case for a coated fitting. In the case of the 90° elbow, the coated fitting gives a lower pressure differential than the uncoated for both emulsion states. The thickened emulsion displays a higher pressure differential than the relaxed state emulsion. This is explainable in that the thicker emulsion, approximating plug flow, is less able to conform to the 90° bend than is the more laminar flow relaxed emulsion.

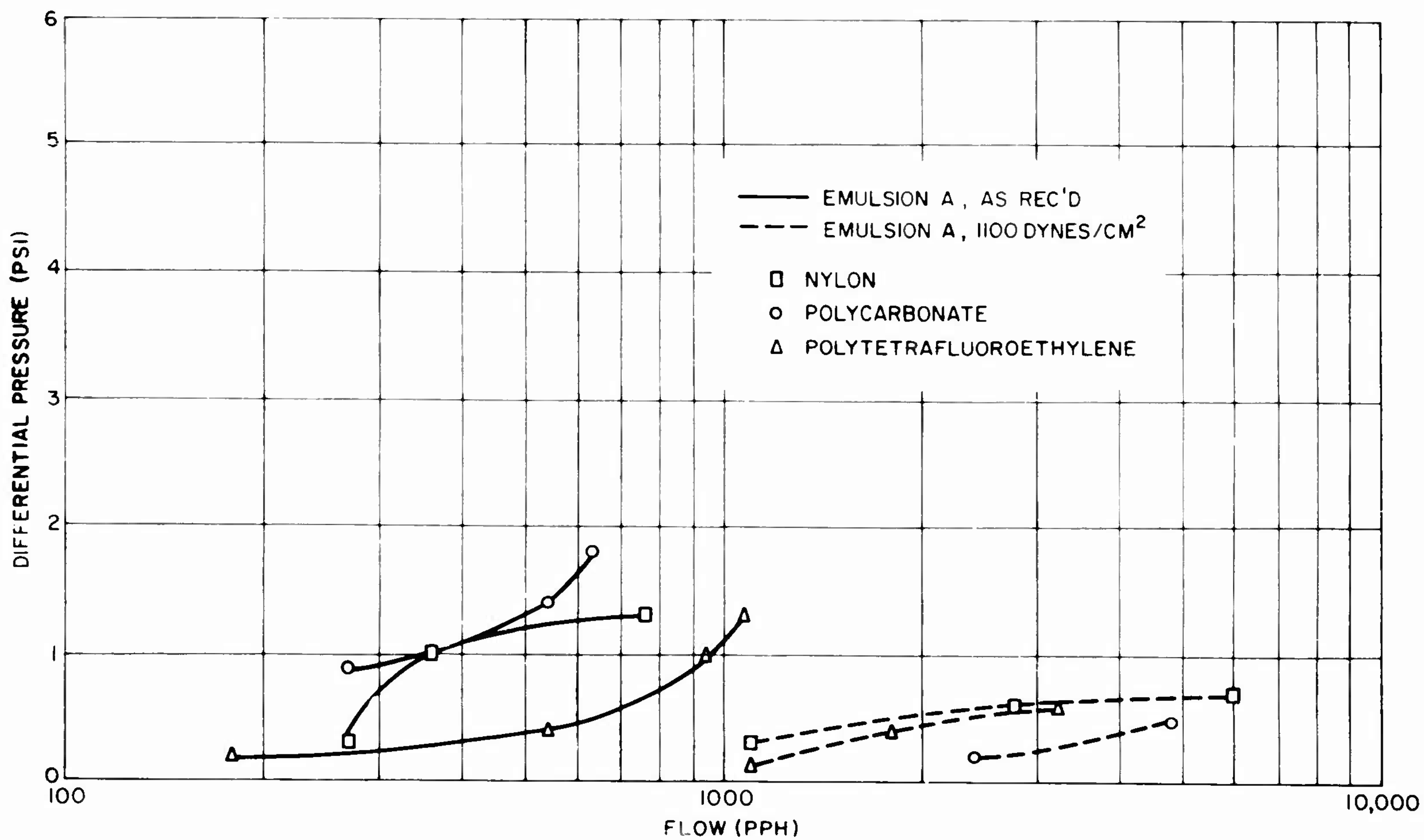

Figure 11. Flow vs Differential Pressure, Emulsion A, 1.0-Inch I.D. Tubing.

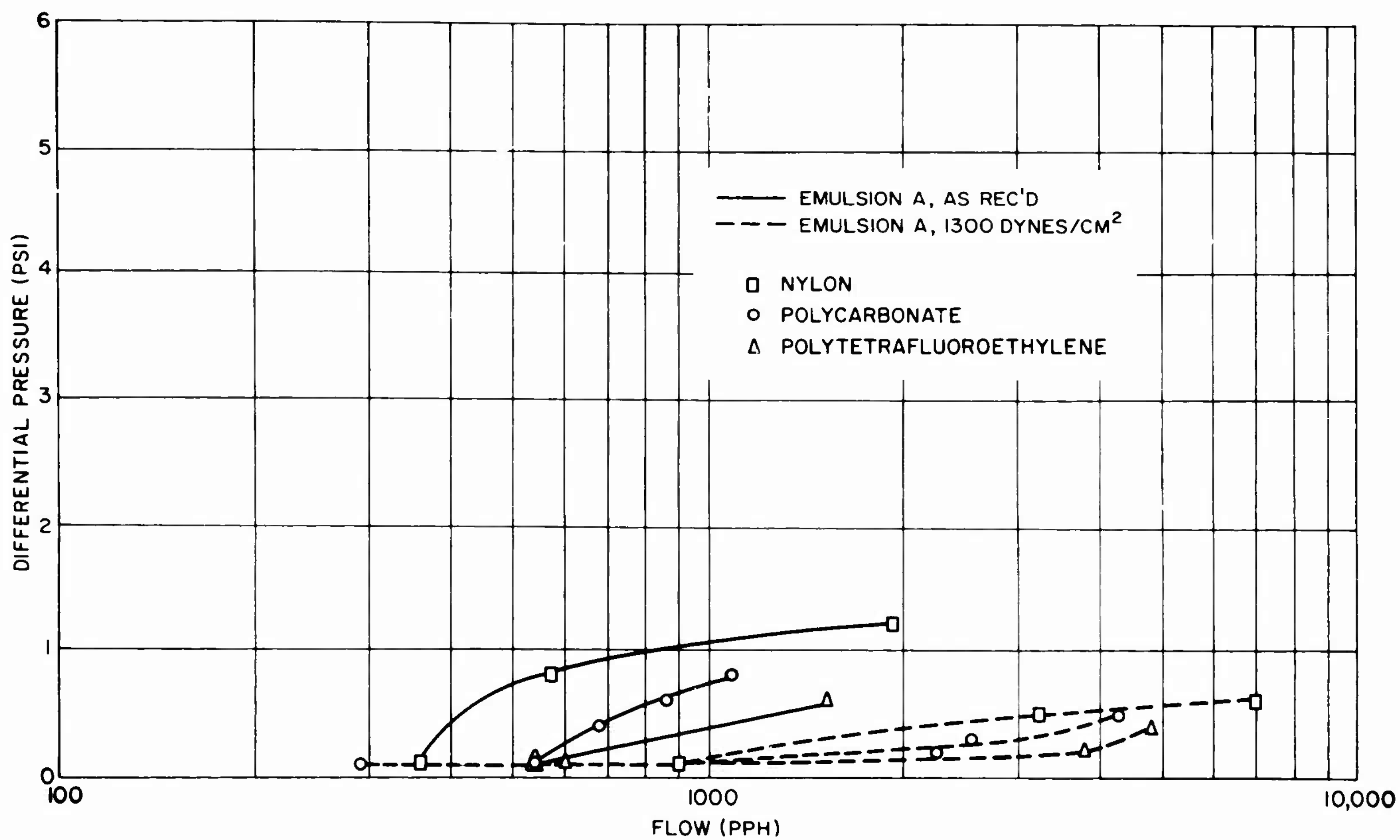

Figure 12. Flow vs Differential Pressure, Emulsion A, 1.25-Inch I.D. Tubing.

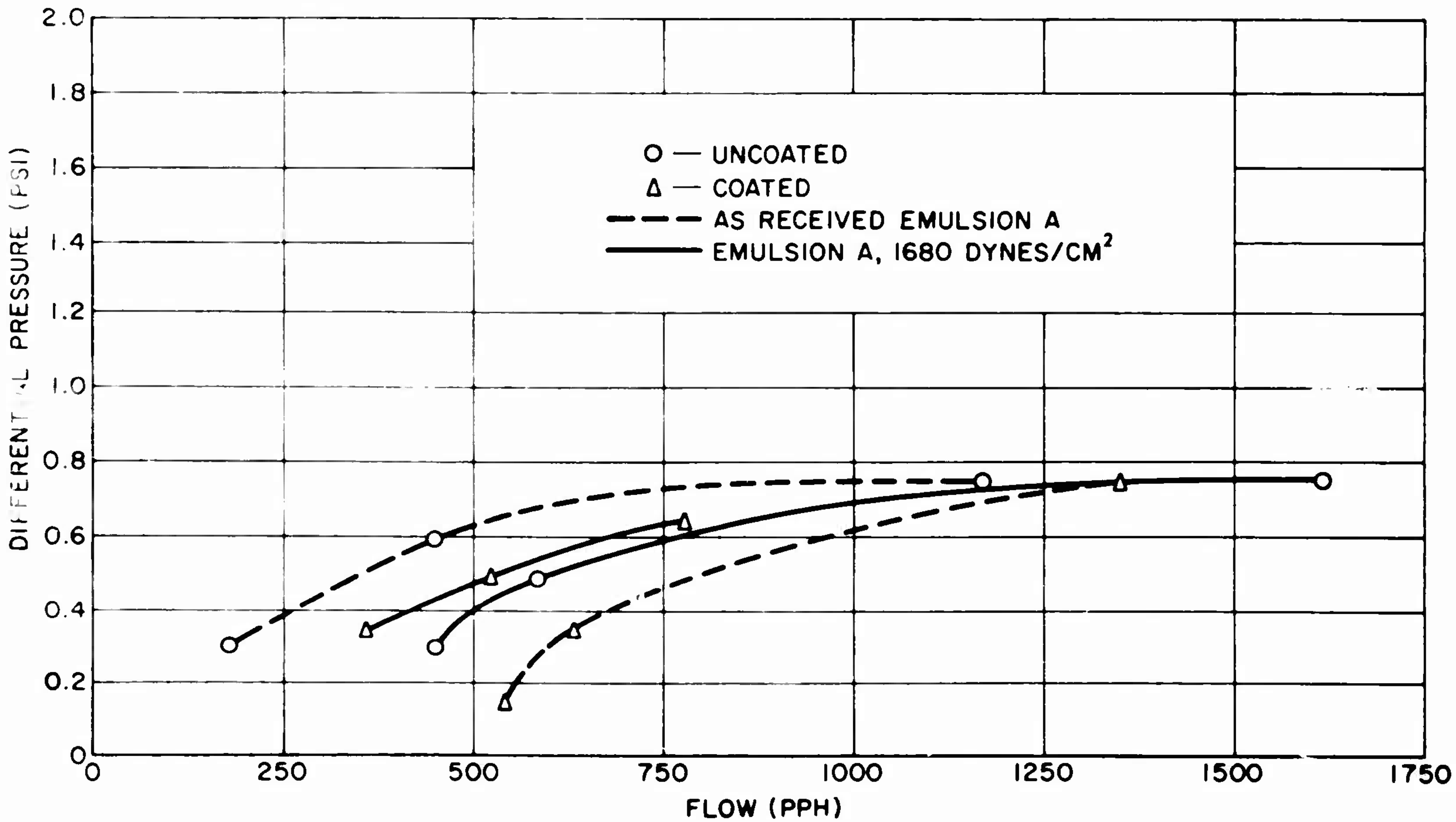

Figure 13. Flow vs Differential Pressure, **Bulkhead Fitting.**

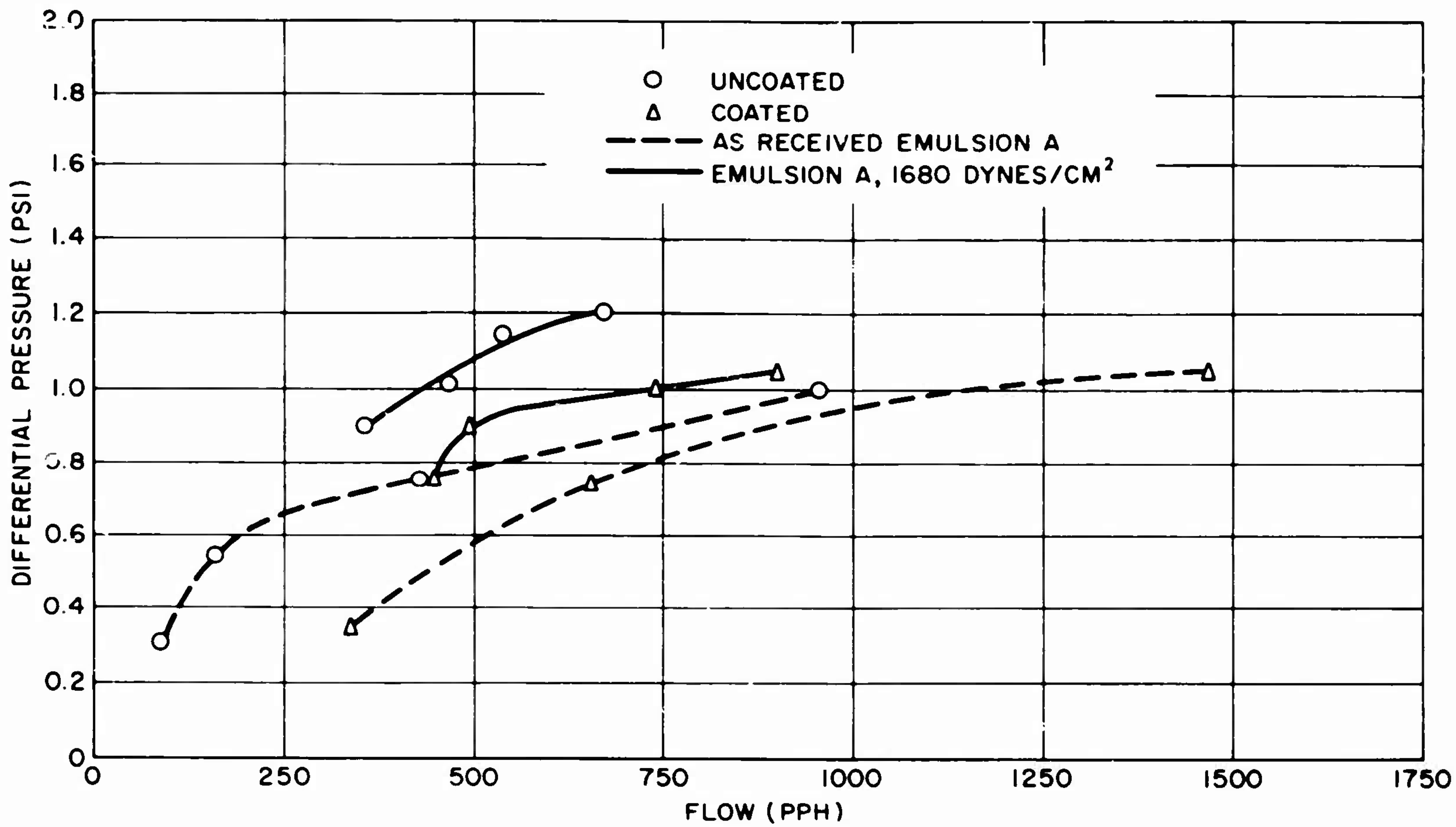

Figure 14. **Flow** vs Differential Pressure, 90° Elbow Fitting.

To minimize pressure drop through the lines of a fuel boost system using emulsified JP-4, the lines should have a 1.0-inch inside diameter and be made of or lined with polytetrafluoroethylene or polycarbonate. There is little added advantage to using lines having 1.25-inch inside diameter. In the case of fittings, there would be an advantage to lining the fittings with polyethylene, polytetrafluoroethylene, or polycarbonate; or, as an alternative, the fittings could be made of these materials.

FUEL BOOST PUMPS

PUMP SELECTION

The fuel boost pumps used in United States Army helicopters are centrifugal pumps, usually operated fully submerged in fuel. The pumps are usually driven by integral dc motors, but in one case the drive is by a 400 Hz, 115 vac motor. Five pumps from two different manufacturers were selected for test. Three of the pumps were types which were in use or which had been used in U.S. Army helicopters, while the remaining two were selected for reason of design or flow and pressure capability. The pumps are shown in their test mountings in Figures 15 through 19.

Pumps A and B are nearly identical in design but were selected for test since they are used in different modifications of the same helicopter. They are driven by 28 vdc motors, and and fluid is taken into the pump from below the impeller. The pump inlets are 3/8 inch in height and cover approximately 180 degrees.

Pump C is powered by a 400 Hz, 115 vac motor,and the fluid is taken into the pump below the impeller. The pump is bracket mounted to give an effective inlet height of 3/4 inch,and the intake covers 360 degrees, although the bracket presents some restriction on the intake. The outlet of this pump incorporates a bypass valve so that fluid need not be pulled through the intake and impeller chamber by the suction from the engine-driven pump in case of boost pump failure.

Pump D is driven by a 28 vdc motor and has an approximately 250-degree, 3/8-inch height intake. In this pump, the fluid is taken in above the impeller,which is not of typical design but has more the appearance of a turbine compressor stage.

Pump E is driven by a 29 vdc motor and has an approximately 210-degree, 3/4-inch height intake. The fluid is taken into the pump below the impeller. This pump is the largest of those tested and was selected for its high flow and increased pressure capability.

PUMP TEST SYSTEM

The test system used to evaluate pump performance with the three test emulsions is shown schematically in Figure 20, while Figure 21 is an overall view of the system. The pump to be tested was mounted in the bottom of Tank A,which was then filled with test emulsion. The emulsion was pumped to Tank B,which was mounted in a support frame to prevent tilting. A bracket on the bottom of Tank B rested on a load cell with a maximum capacity of 2000 pounds and which, in turn, was mounted on a hydraulic jack. With the jack in the raised position,the weight of Tank B was on the load cell. Figure 22 shows the mounting of Tank B and the load cell. Tank B contained a boost pump which was not one of

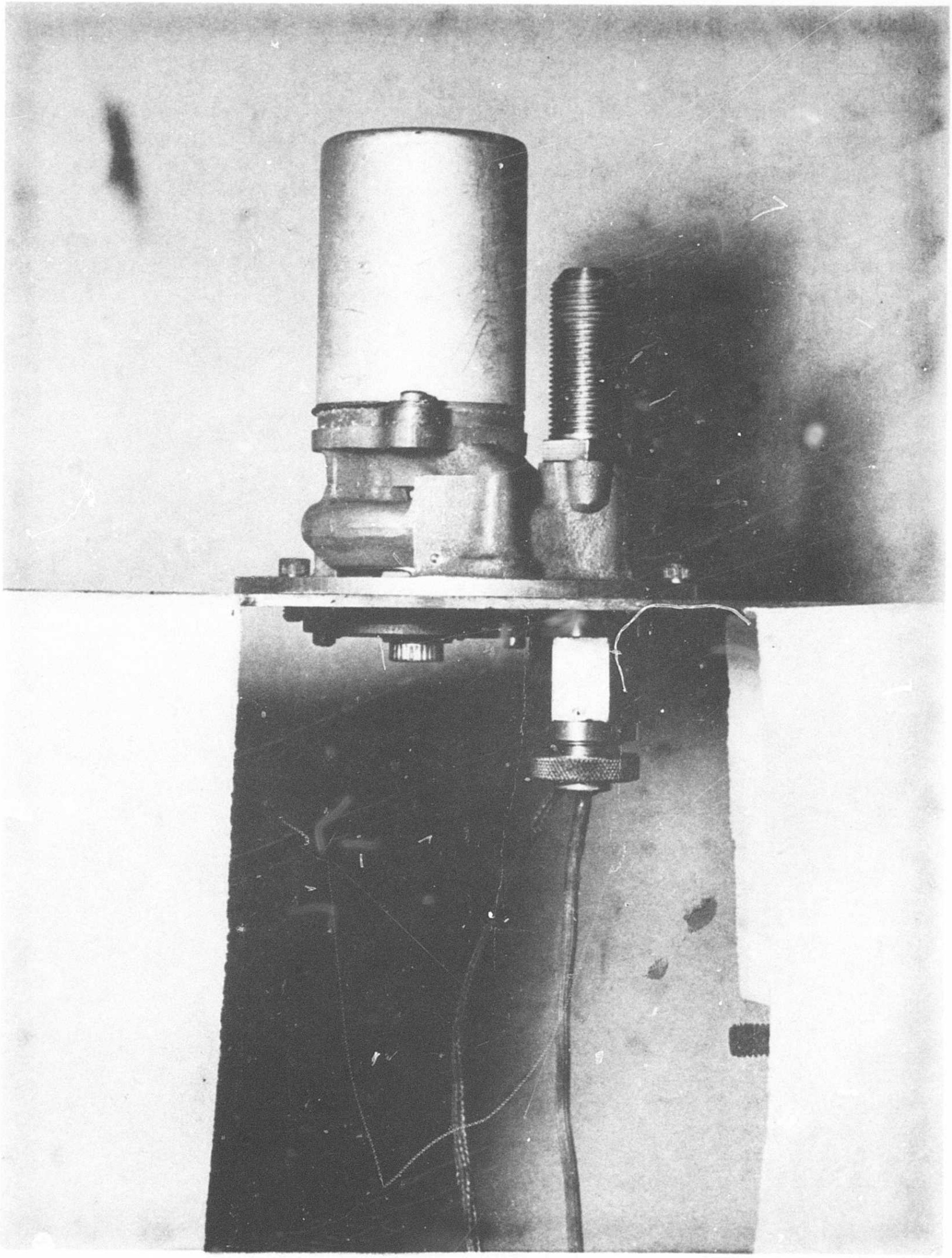

Figure 15. Boost Pump A.

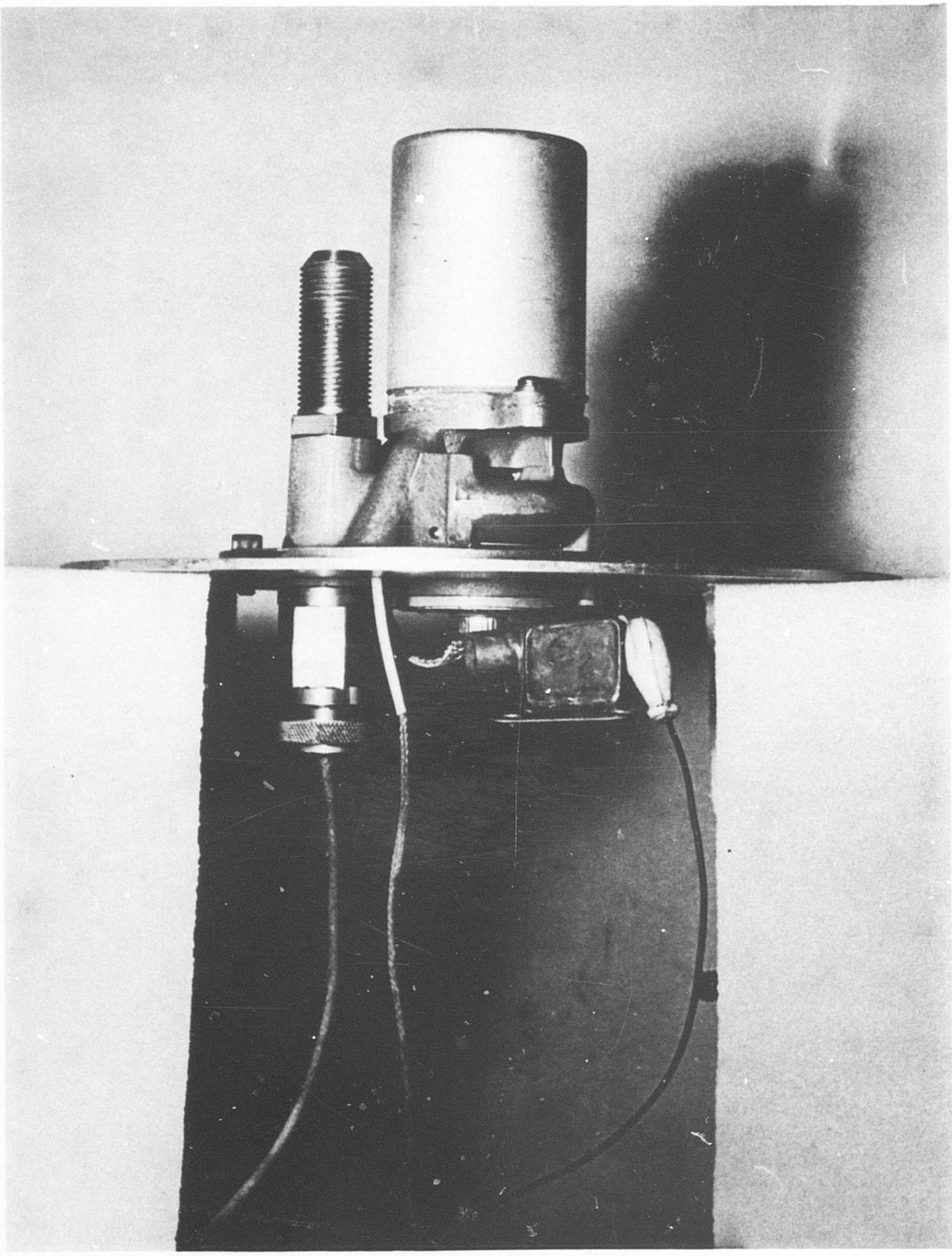

Figure 16. Boost Pump B.

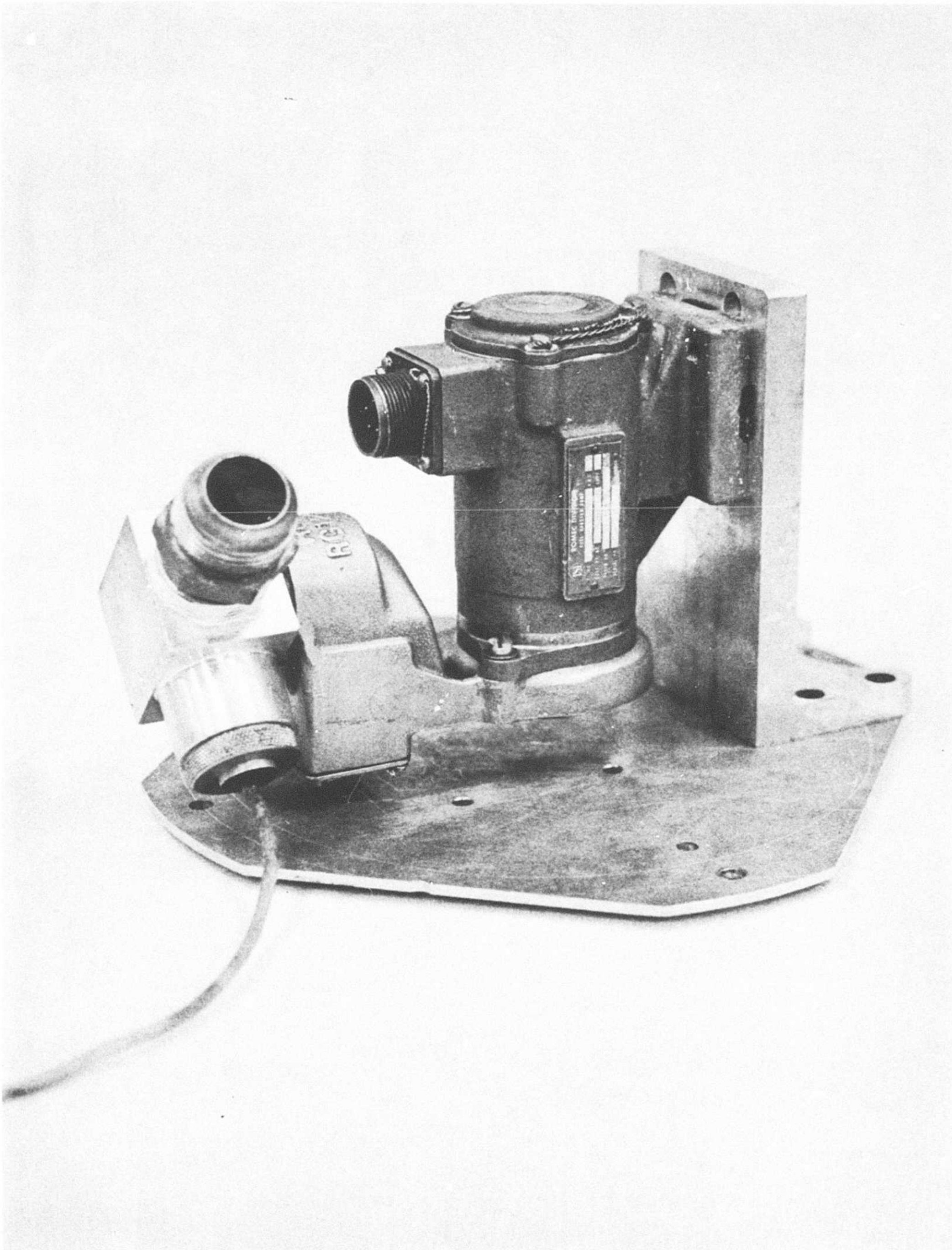

Figure 17. Boost Pump C.

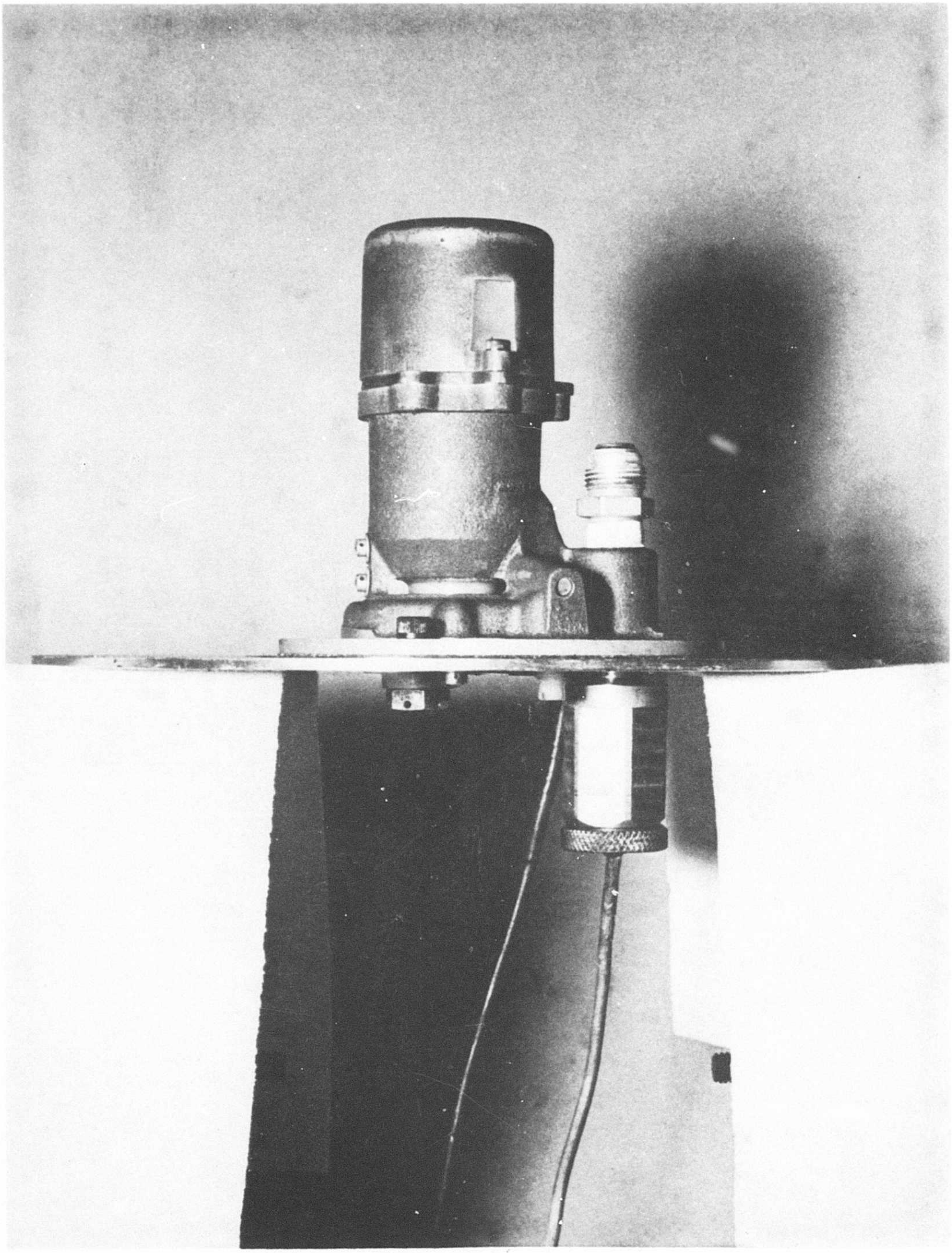

Figure 18. Boost Pump D.

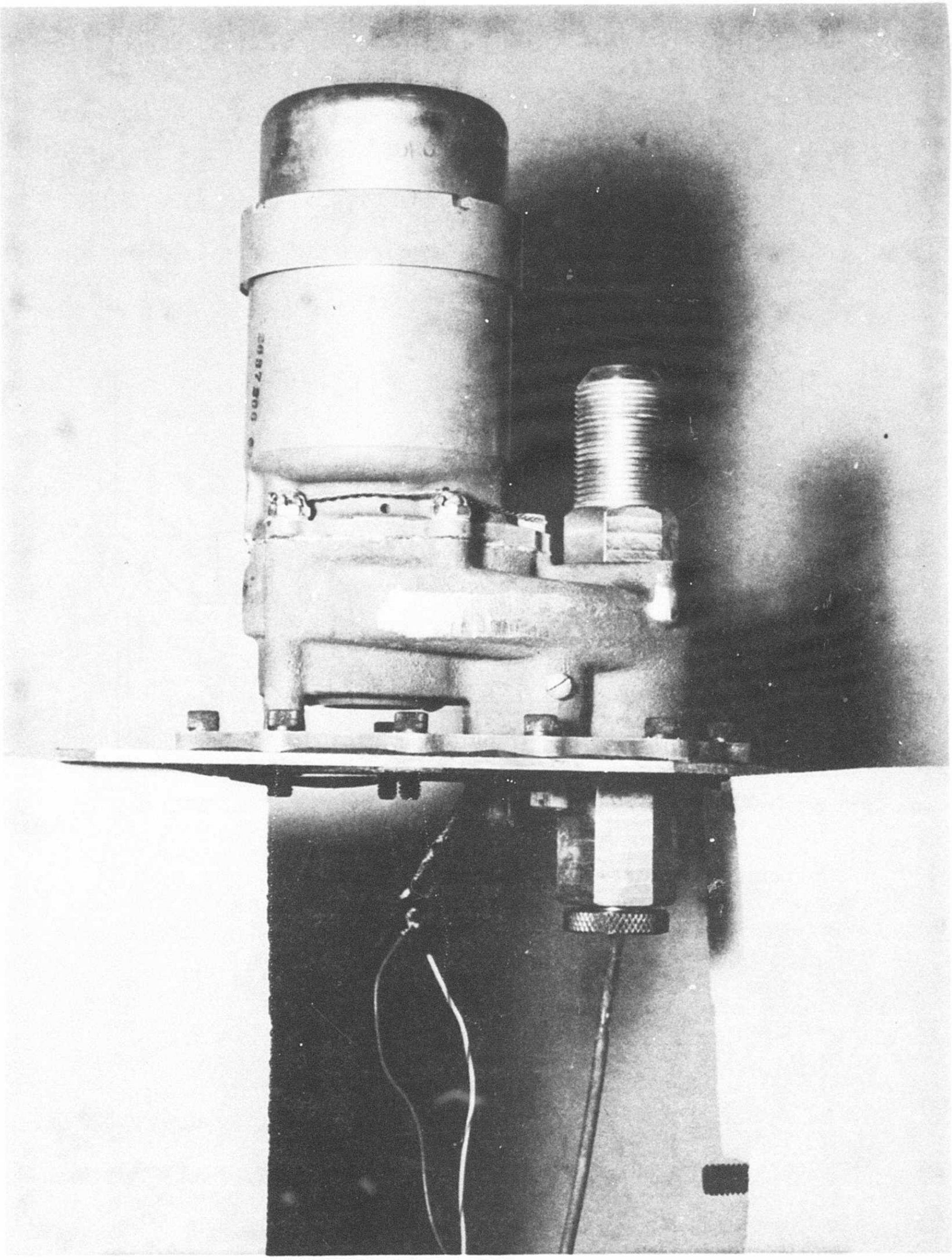

Figure 19. Boost Pump E.

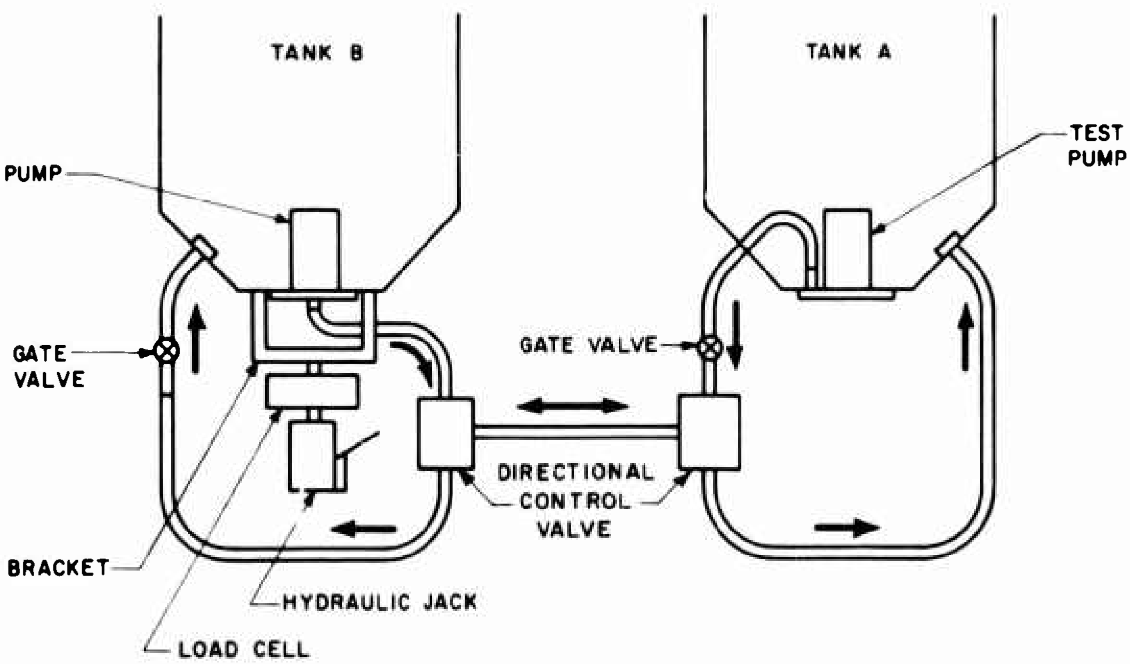

Figure 20. Boost Pump Test System.

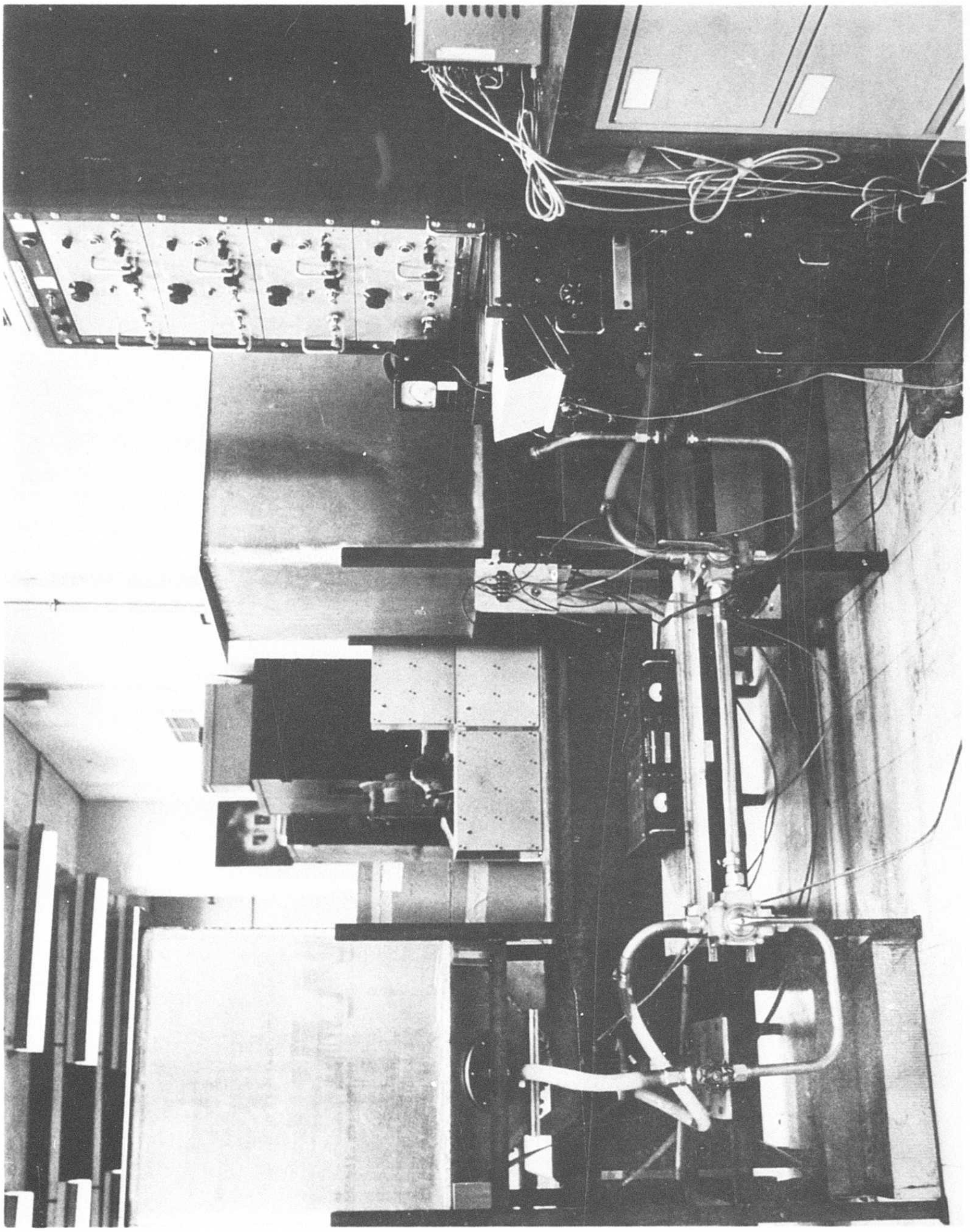

Figure 21. Pump Test System.

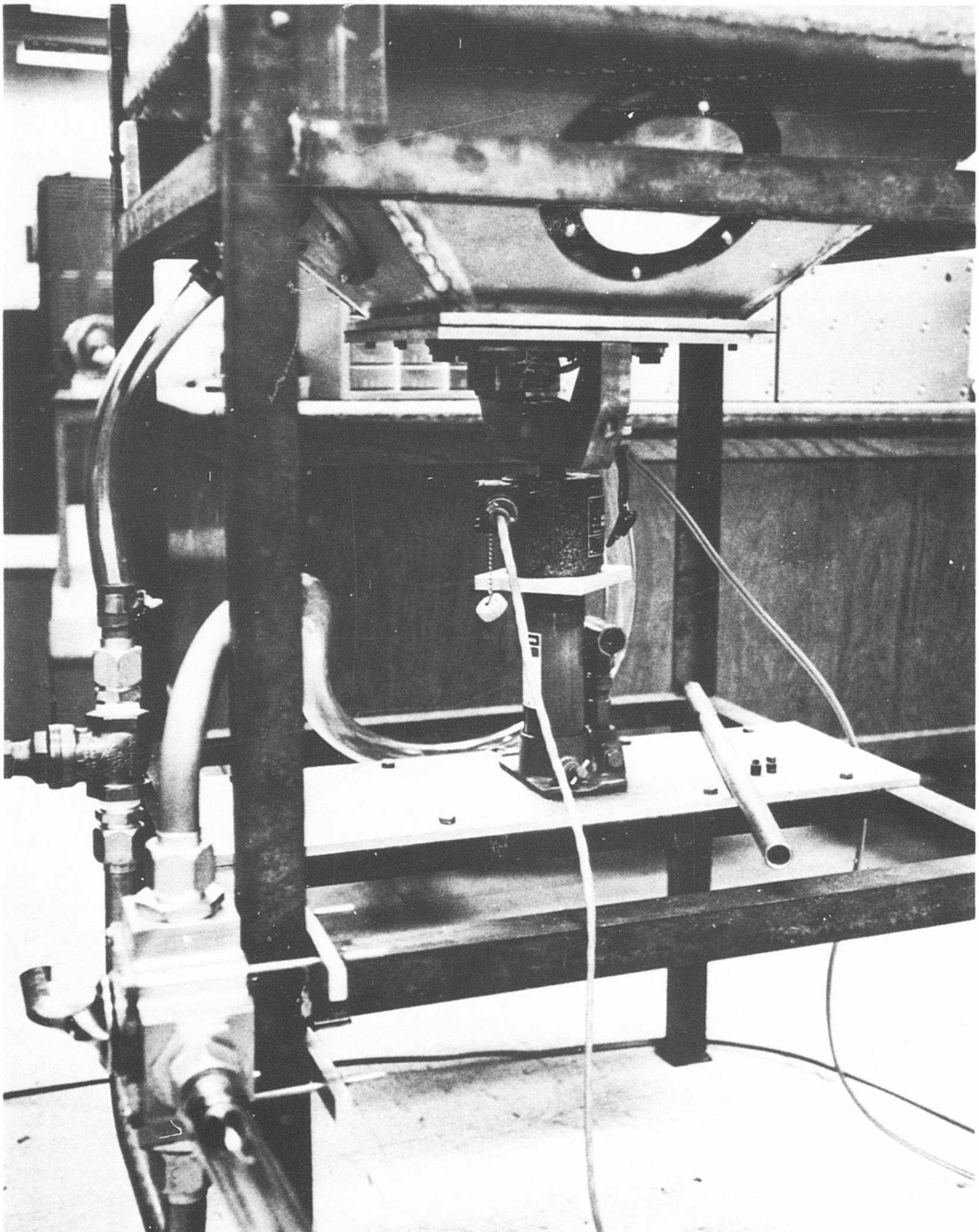

Figure 22. Tank B and Load Cell Mounting.

the test pumps; this pump was used to empty Tank B either to a drum or back to Tank A. Flow direction was controlled by means of directional control valves of a circular plug type having very large plug openings to give a minimum valve pressure drop. Flow and pressure were controlled by means of gate valves in the outlet lines. Electrical power for the pumps was furnished by a regulated 28 vdc supply for the dc motor-driven pumps and by a 28 vdc to 400 Hz, 115 vdc inverter for the ac motor-driven pump. Measurements of flow rate in pounds per hour, pressure in psi, input voltage, and current in amperes were made continuously during tests. Flow was measured by recording the load cell output on a time base recorder. The slope of the line produced by this recording was used to determine flow rate. A 0 to 50 psia strain gauge transducer, flush face type, was mounted in the pump outlet,and the recorded output from the transducer gave the measurement of pressure head. Since an absolute pressure transducer was used, the same unit gave readings for suction in the failed pump tests. Voltage was measured across the input leads at the pump and recorded, and current was measured by recording the voltage drop across a 1-ohm resistor. AC voltages and currents were not recorded but were measured by precision meters. A schematic drawing of the measuring system is given in Figure 23. A reaction torque transducer was used at the beginning of the tests to measure pump torque, but vibration during operation of the pumps gave recorder traces with excessive signal to noise ratios and the measurements were discontinued.

FLOW AND PRESSURE TEST RESULTS

The flow and pressure relationships were determined for each of the five test pumps with the three test emulsions and with JP-4. Figures 24 through 28 show the results of the tests. Emulsion C could be pumped only by Pumps C and D and then only in small amounts. Emulsion B gave pump performance closest to that with JP-4 with all pumps. Emulsion A could be pumped but with reduced efficiency and a decreased maximum output. Pump overall efficiencies calculated from the electrical input and hydraulic output horsepower are shown in Figures 29 through 33.

FAILED PUMP TEST RESULTS

The vacuum required to draw emulsified fuels through the test pumps was determined as a function of flow rate. Emulsion C was not used in these tests since it could not be pumped in significant amounts. The results of the tests are shown in Figures 34 and 35. The significant results are the behaviors of Pumps C and E with both emulsions. In the case of Pump C, the bypass operation produces a considerable flow enhancement; and in the case of Pump E ,the larger inlet and impeller chamber allow flow with low vacuum. It is also worth noting that Emulsion B requires somewhat higher vacuum than Emulsion A. Since impeller operation would shear the emulsion, it is possible that the excellent pumping behavior of Emulsion B is a result of a partial breaking of the emulsion. This would not occur under the conditions of the failed pump tests ,and the higher yield value of Emulsion B would require higher vacuum for equivalent flows.

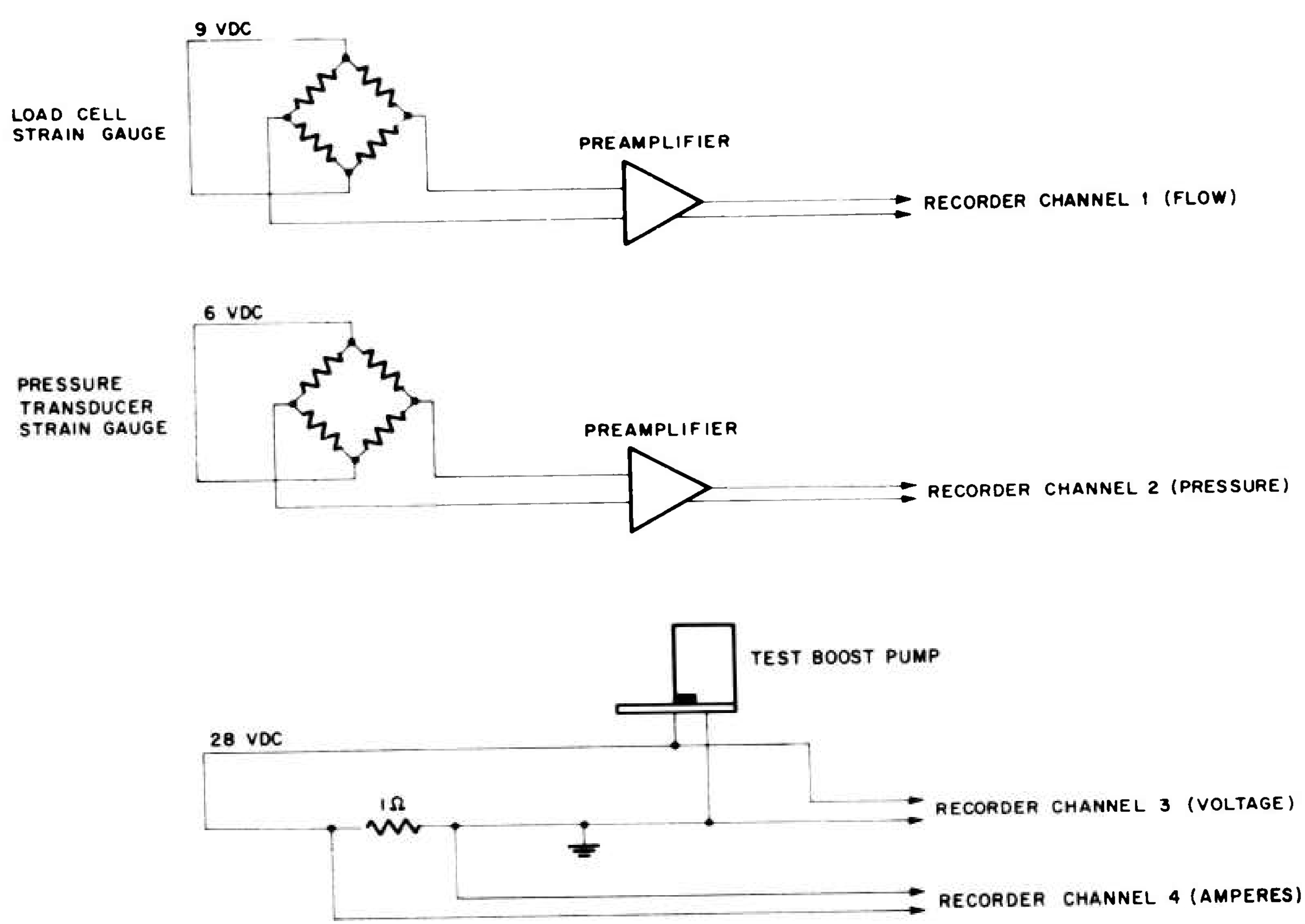

Figure 23. Measuring Systems for Boost Pump Tests.

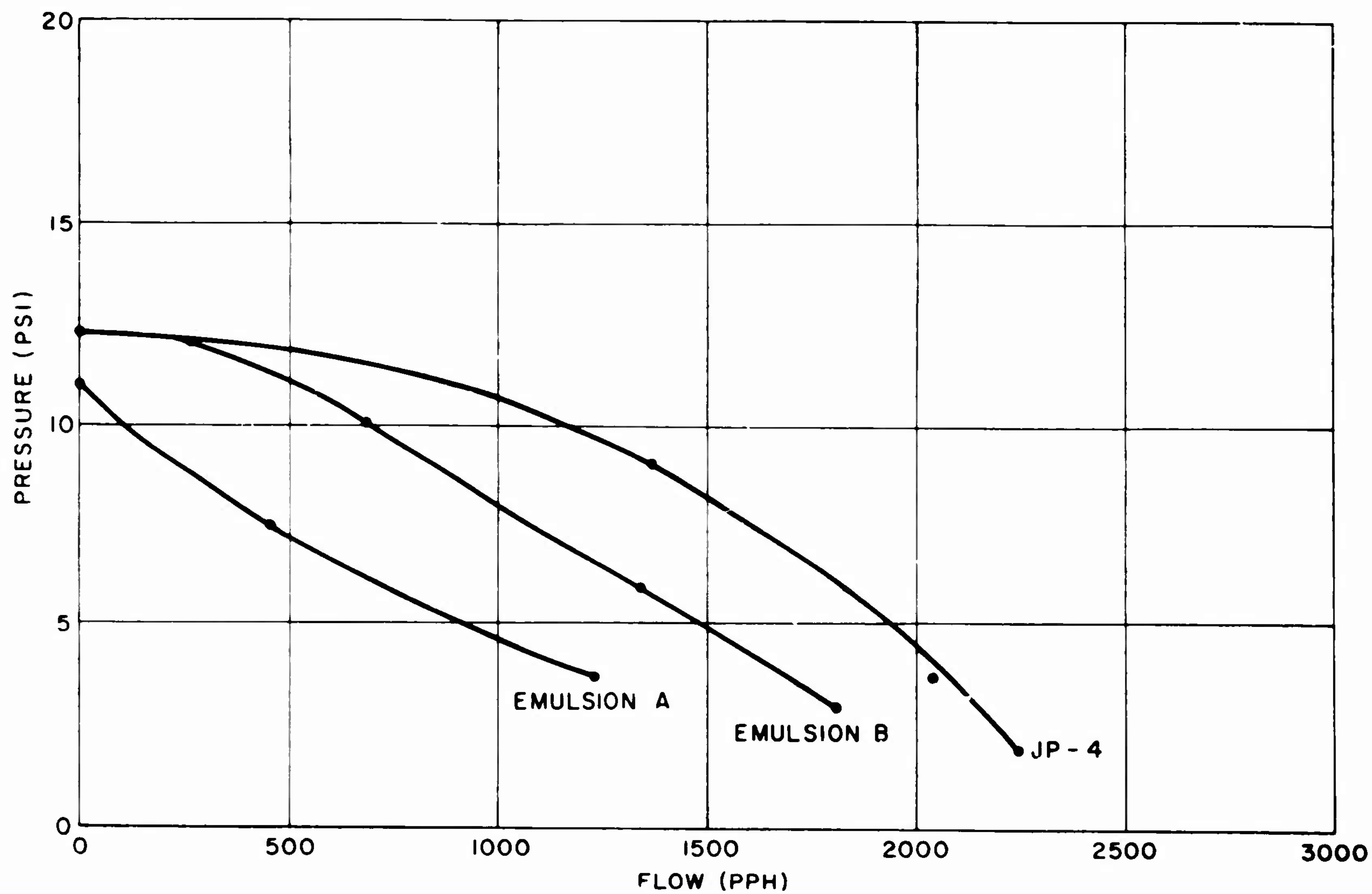

Figure 24. Flow vs Pressure Head, Boost Pump A.

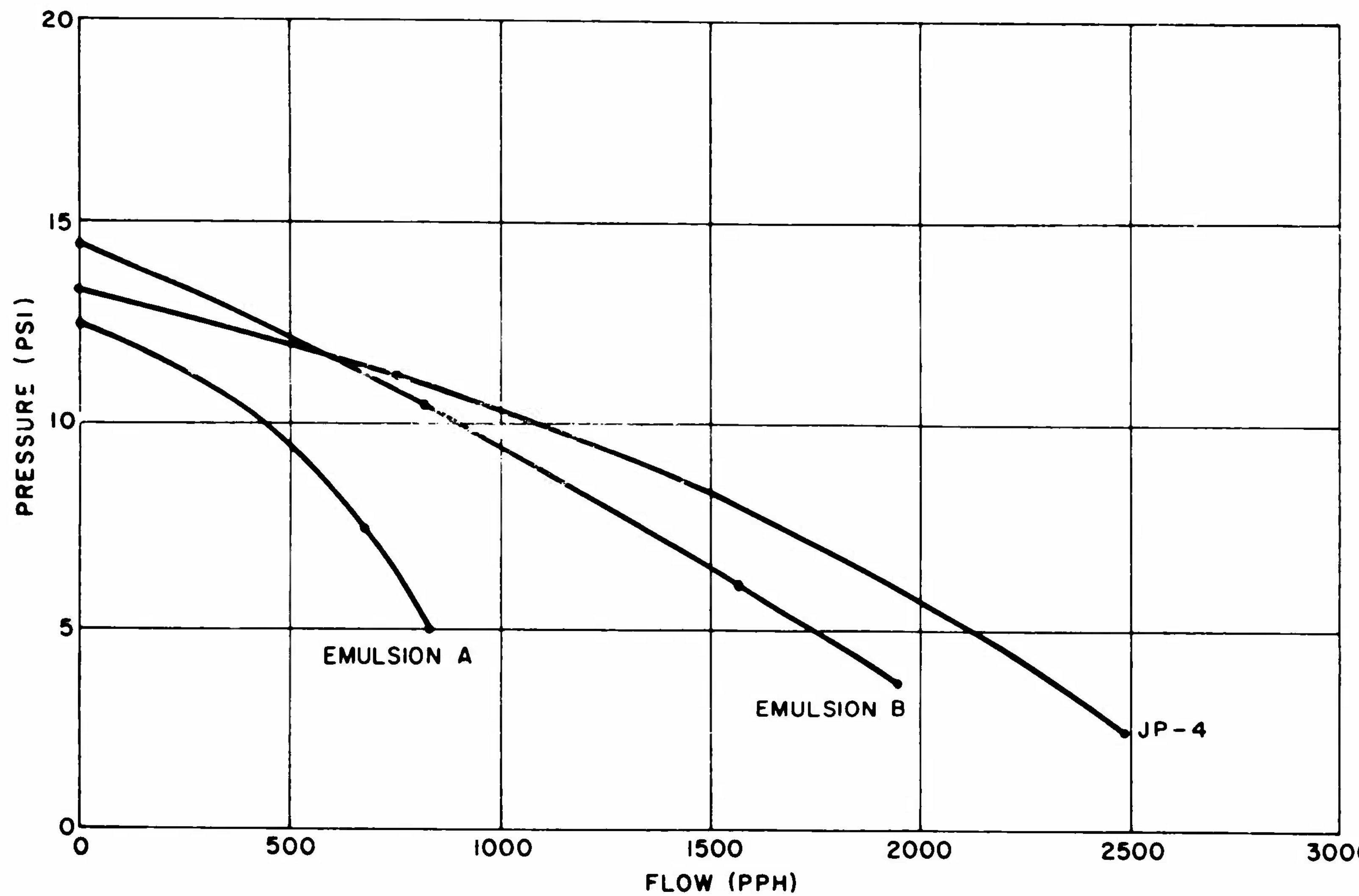

Figure 25. Flow vs Pressure Head, Boost Pump B.

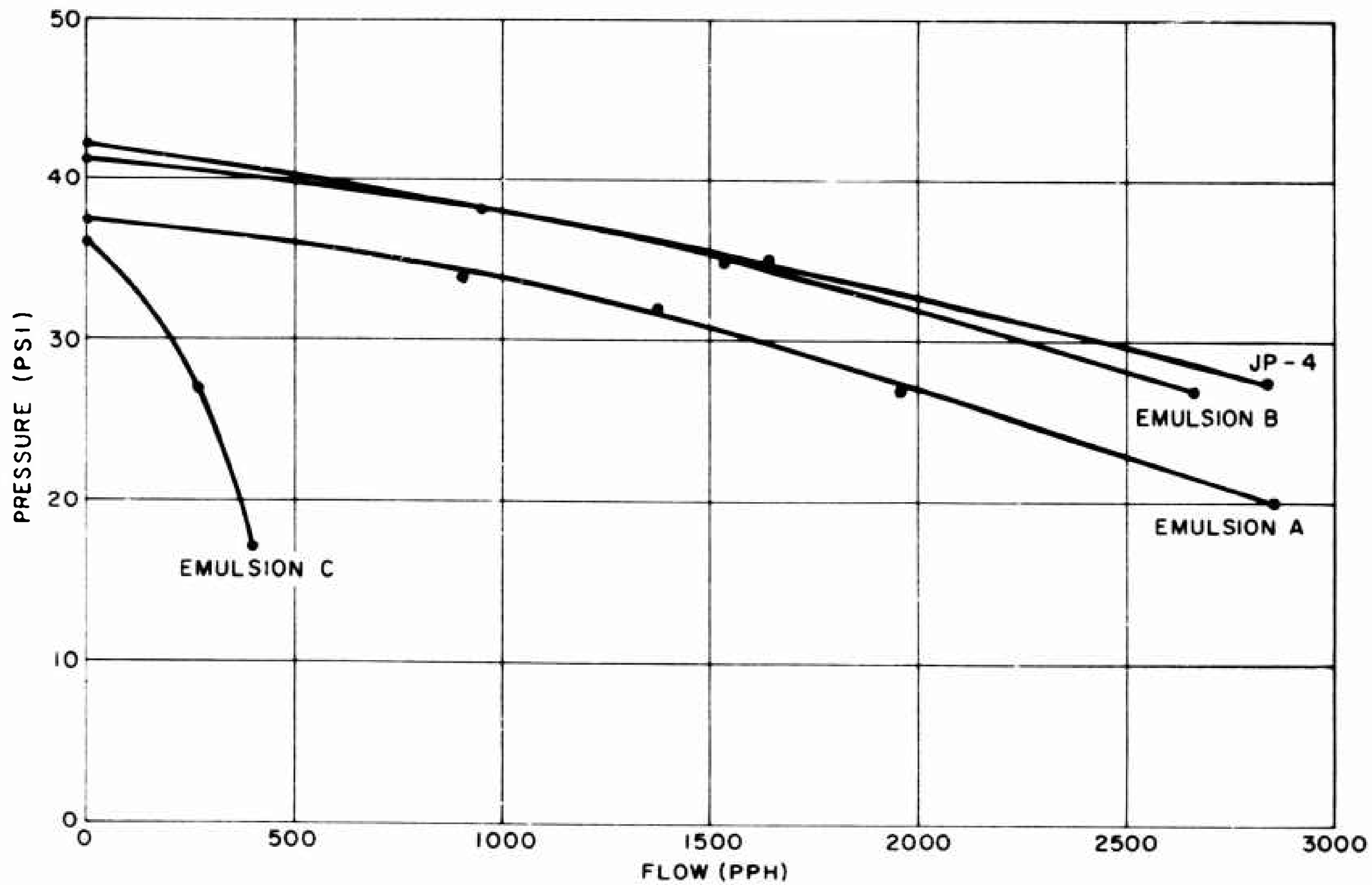

Figure 26. Flow vs Pressure Head, Boost Pump C.

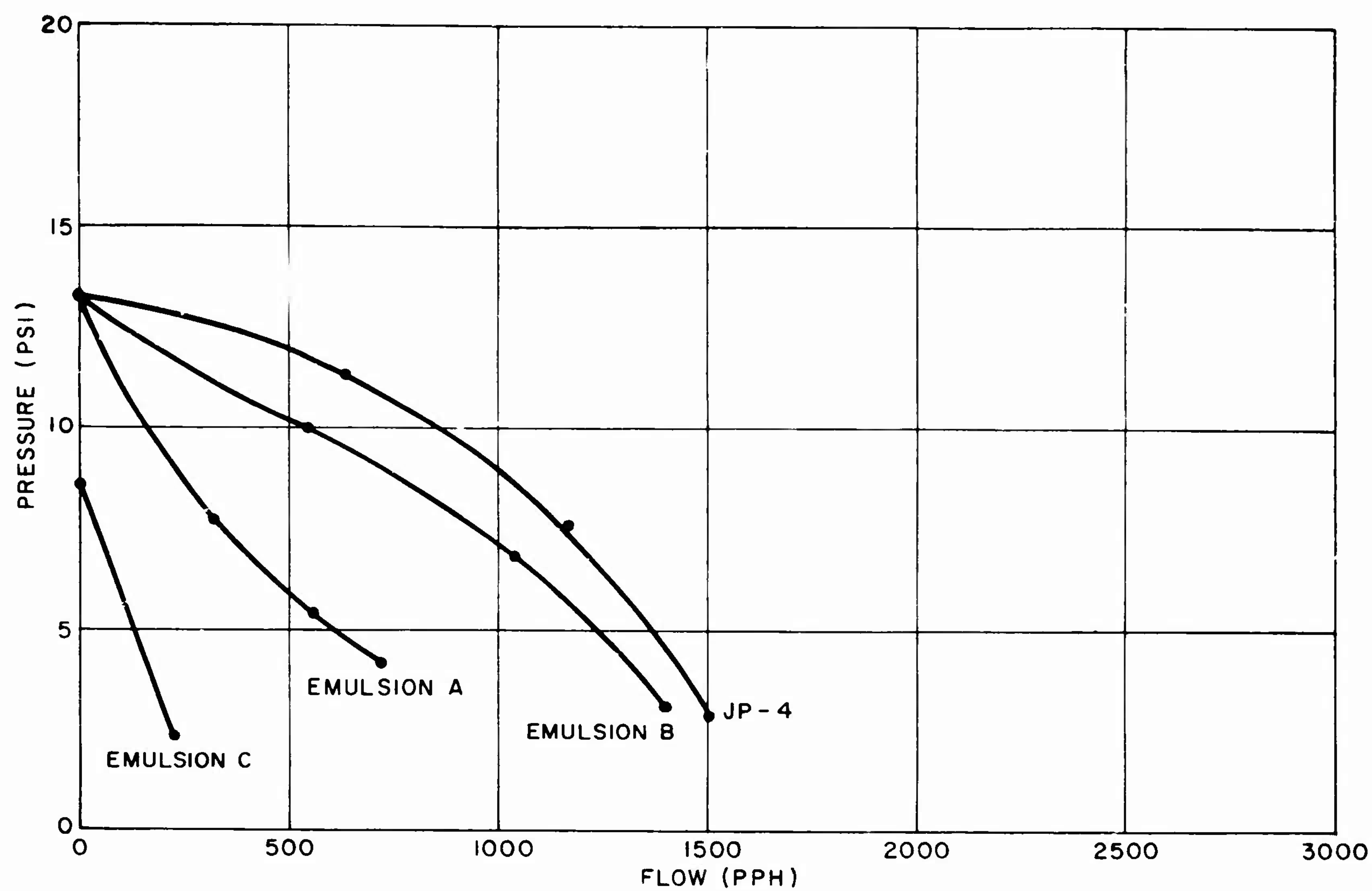

Figure 27. Flow vs Pressure Head, Boost Pump D.

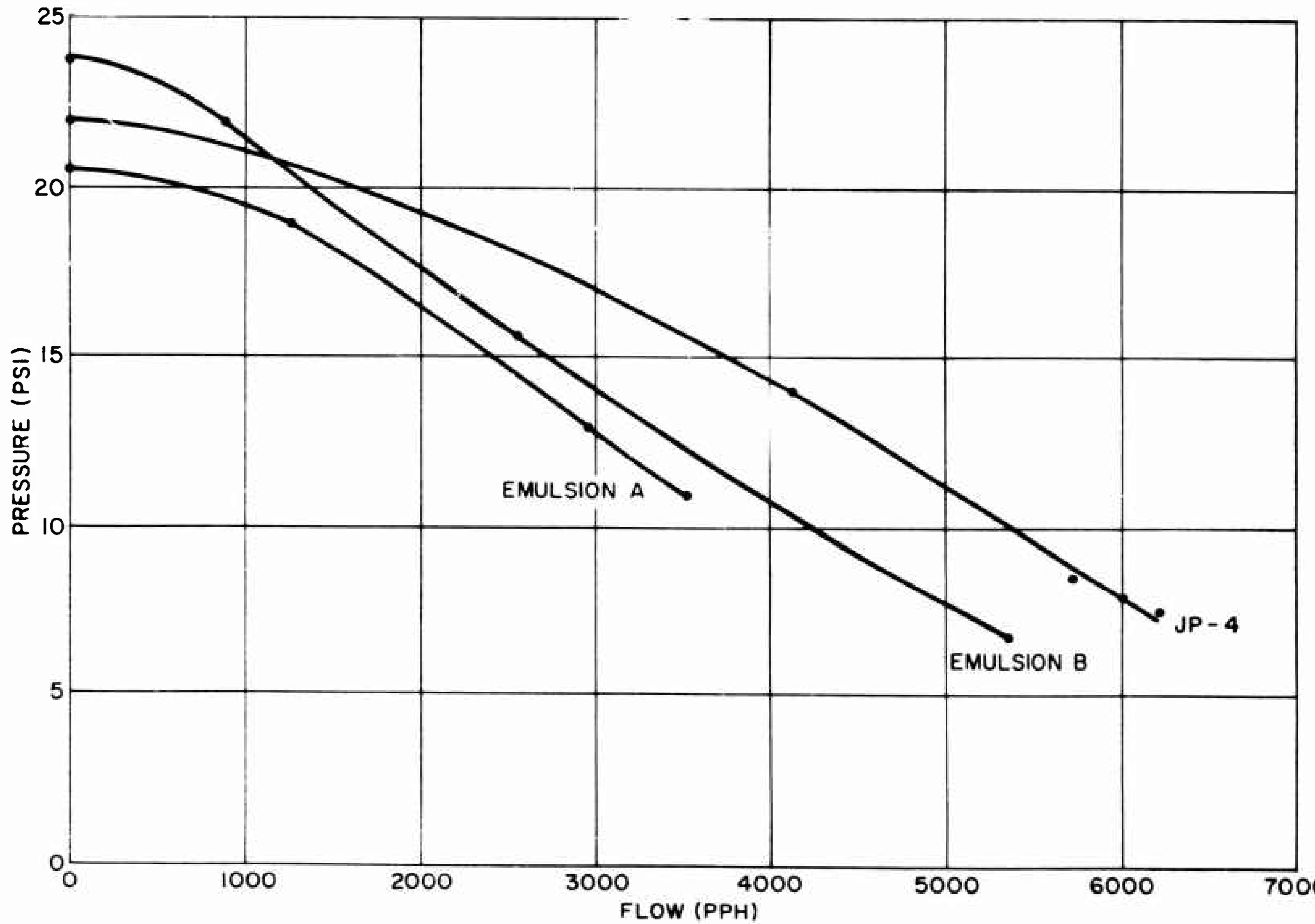

Figure 28. Flow vs Pressure Head, Boost Pump E.

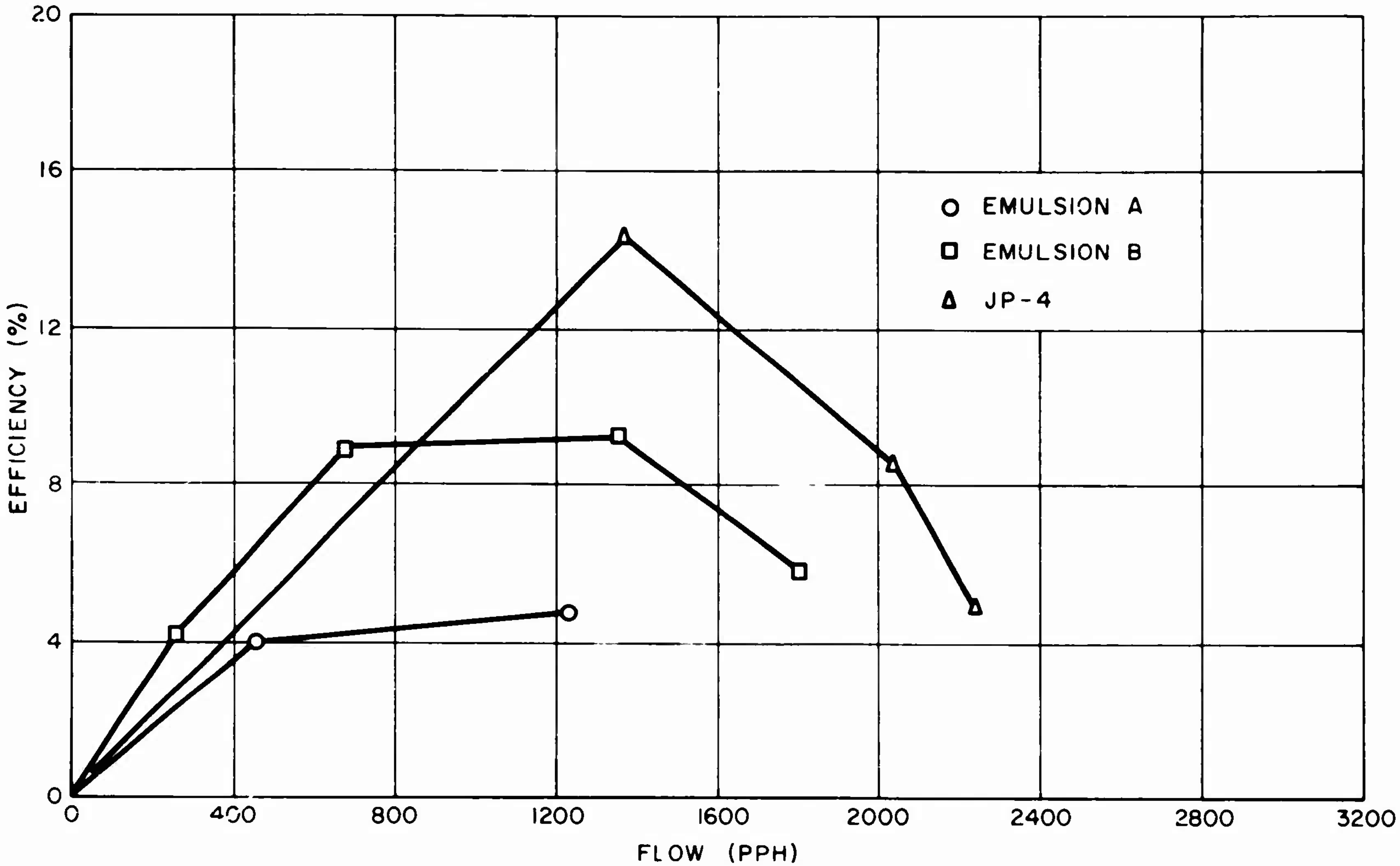

Figure 29. Efficiency vs Flow, Boost Pump A.

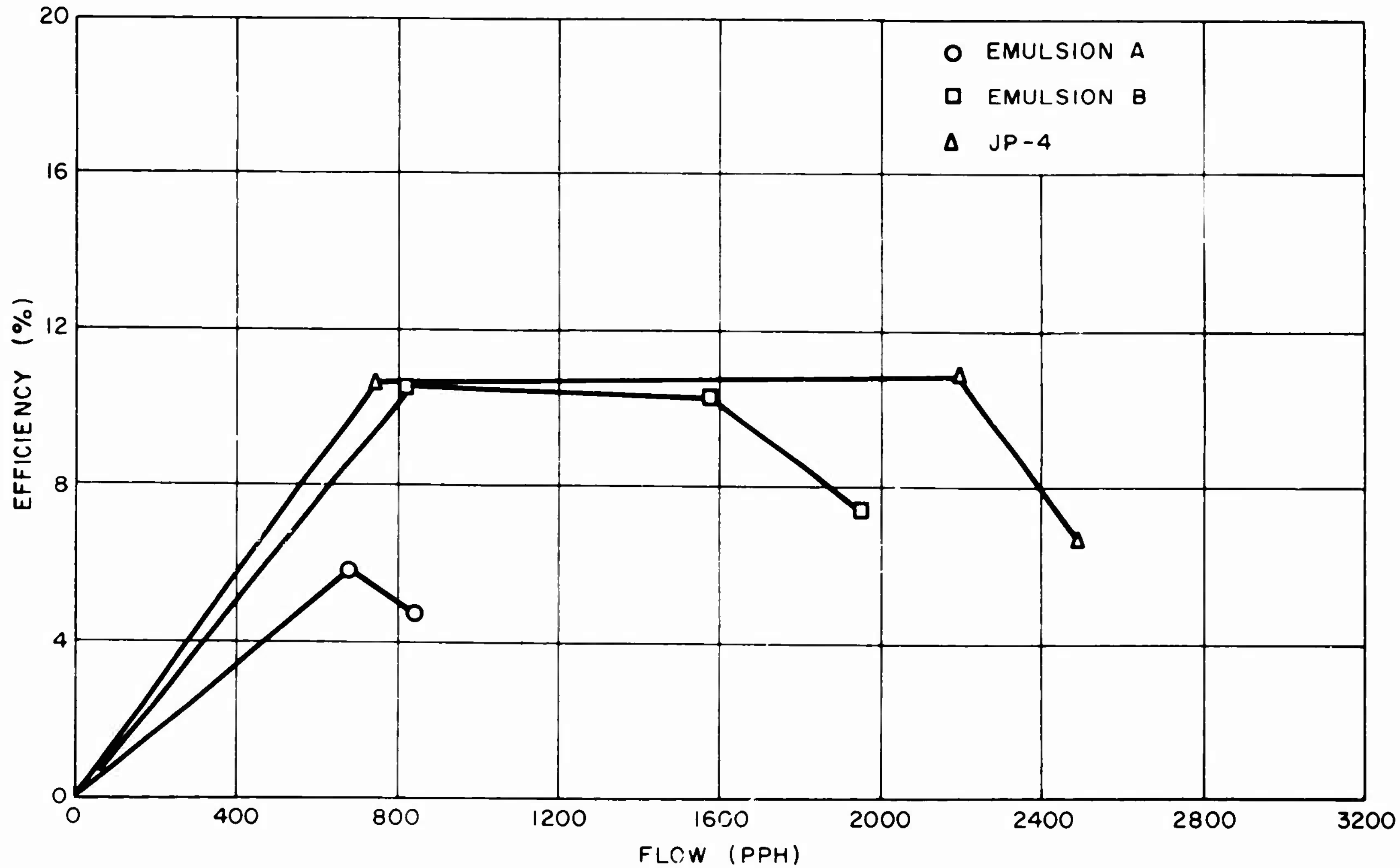

Figure 30. Efficiency vs Flow, Boost Pump B.

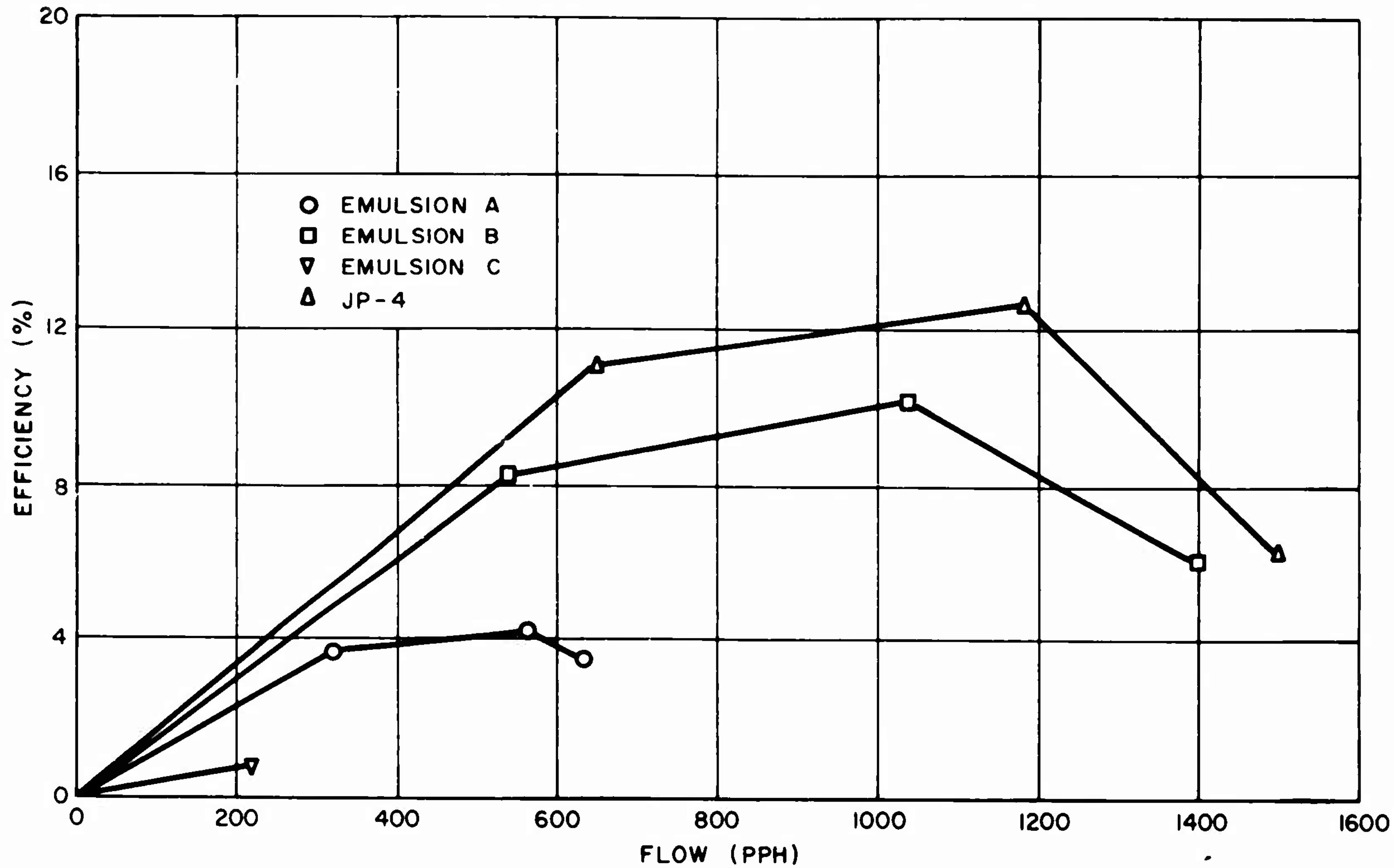

Figure 31. Efficiency vs Flow, Boost Pump C.

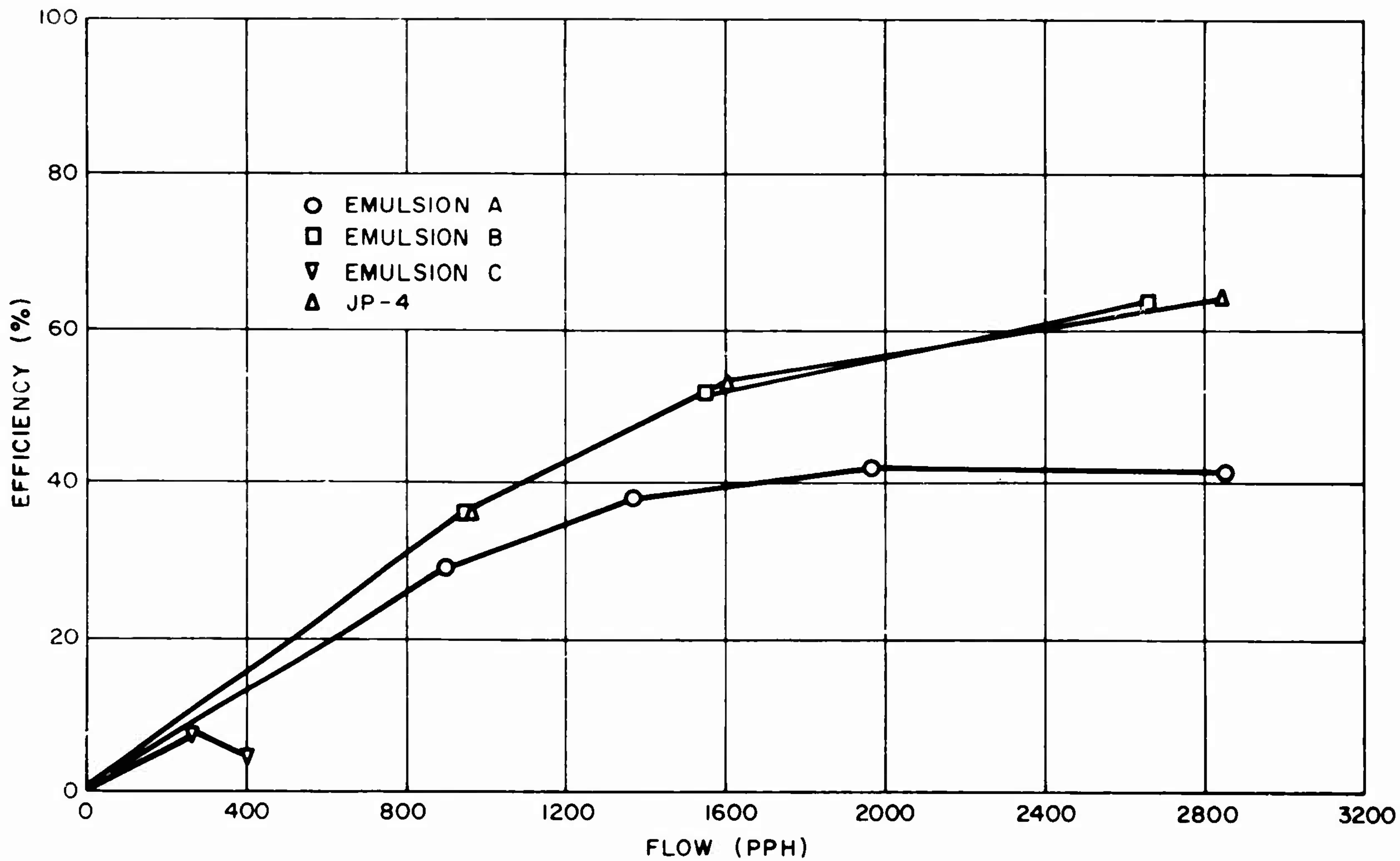

Figure 32. Efficiency vs Flow, Boost Pump D.

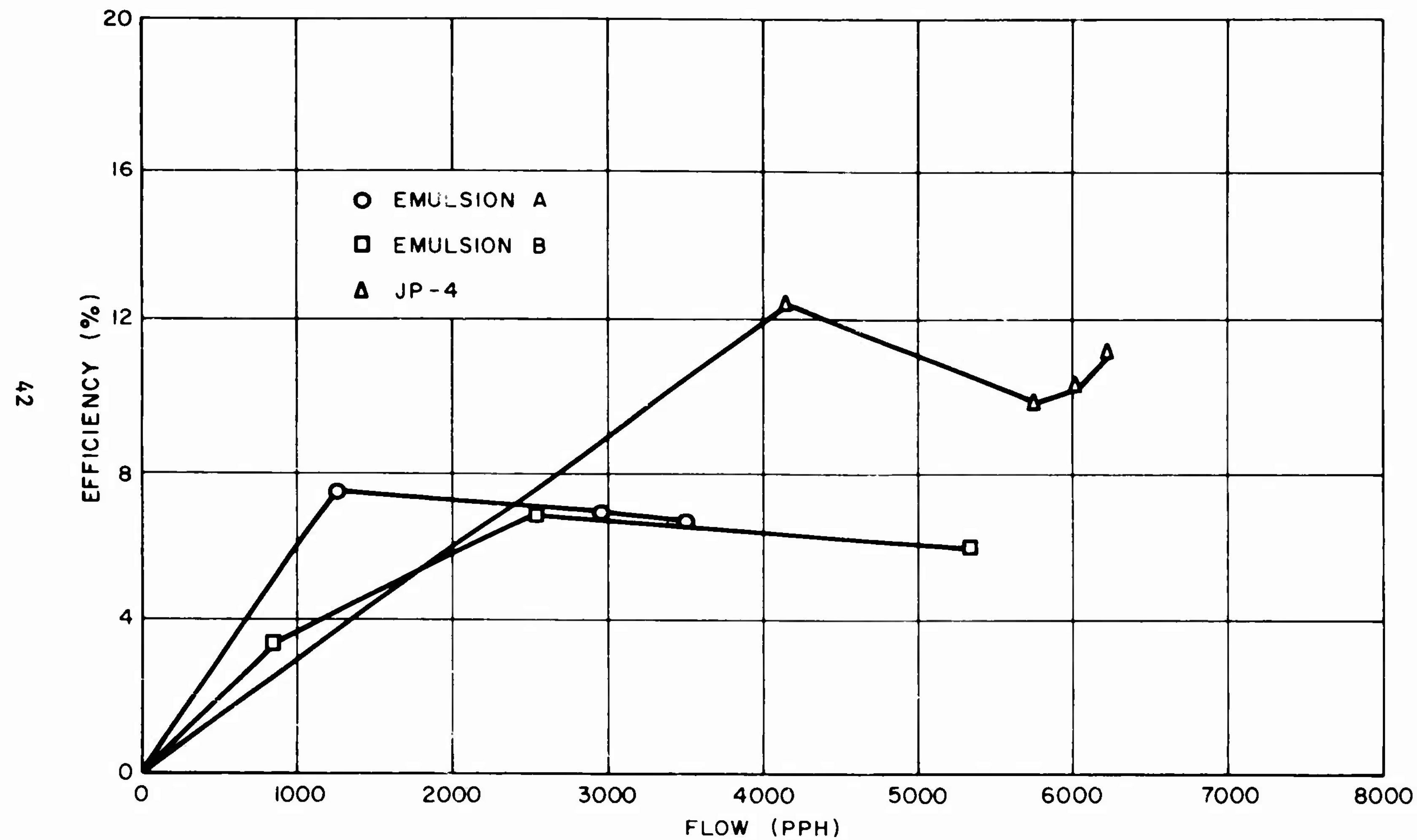

Figure 33. Efficiency vs Flow, Boost Pump E.

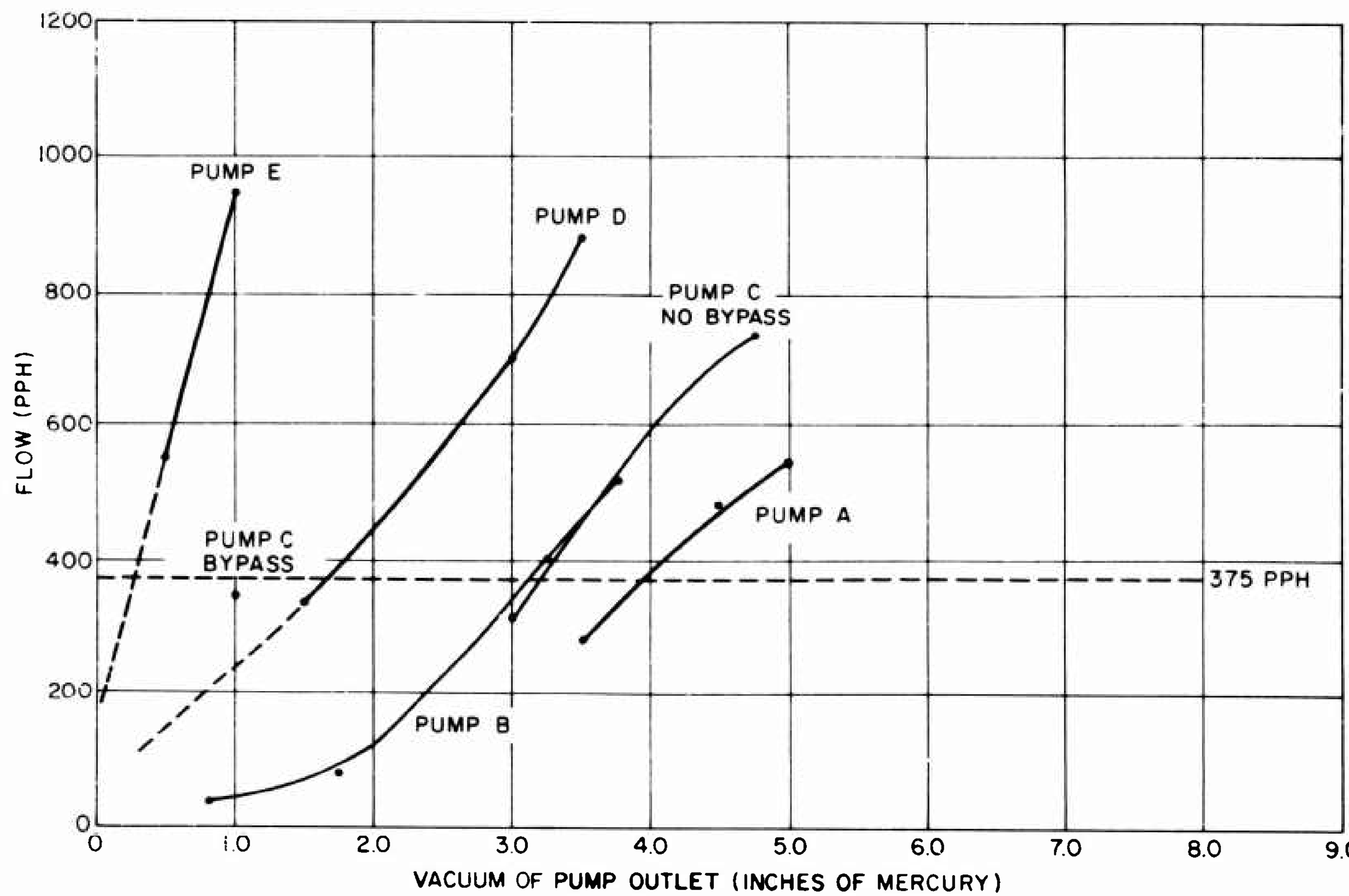

Figure 34. Flow vs Vacuum Requirements, Emulsion A.

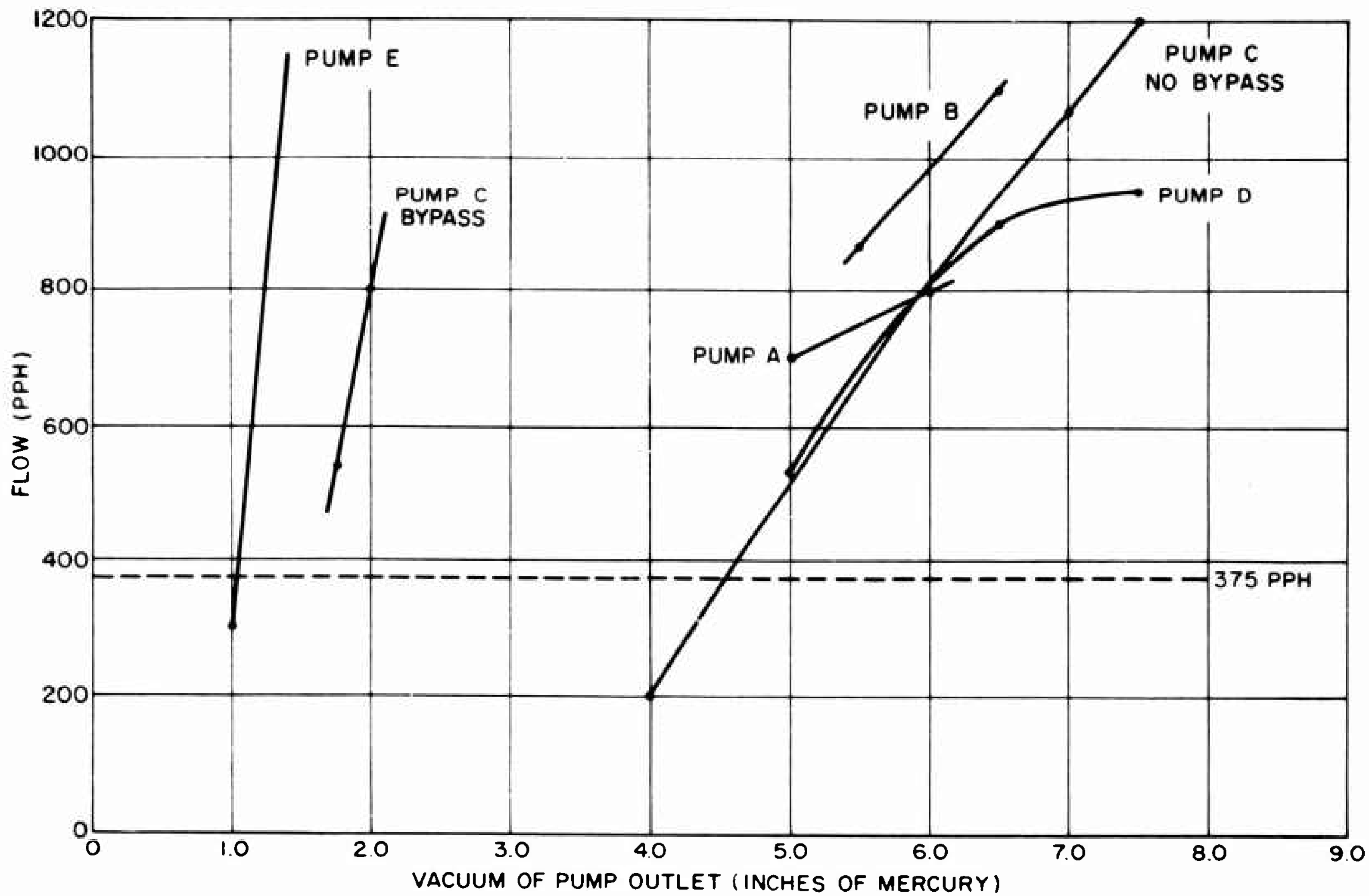

Figure 35. Flow vs Vacuum Requirements, Emulsion B.

TEST RESULTS WITH INCREASED YIELD EMULSION

Additional tests were carried out using Emulsion A with varying degrees of increased yield value and using Pumps A, B, D, and E. Pump C was not used since, in this test, the pump power requirements exceeded the capability of the 400 Hz power source. The emulsion was pumped from Tank A to Tank B by the test pump, after which the emulsion was pumped back to Tank A by the large Tank B pump. The yield value of the emulsion increased as a result of each pumping cycle, and the cycles were continued until emulsion breakage was evident. Generally, emulsion breakage occurred in the region of 1700 to 1800 dynes/cm^2 yield value. The results are shown in Figures 36 through 39.

In the case of Pump E, after the second run, the yield value increased to 1900 dynes/cm^2 when the emulsion was pumped back to Tank A. The partly broken emulsion appeared to reconstitute itself during the return pumping, and the high yield was obtained. At this yield value the pump would not prime and the third run could not be made.

In run number five for Pump A, the emulsion appeared to be breaking and the yield value decreased slightly. Some erratic pressure and flow were observed under these conditions.

The tests indicate that these pumps can handle the increased yield emulsion nearly as well as the as-received emulsion, but, if yields above 1700-1800 dynes are used, difficulty will be encountered with priming.

RESULTS WITH SCREW TYPE PUMP

The results of tests carried out with a screw type pump are shown in Figure 40. This type of pump was expected to be superior to the centrifugal pumps with regard to pumping at low flows and higher pressure. The centrifugal pumps produced partial emulsion breaking under these conditions because of high rotating speed. The screw-type pump operates at much lower speed and, it was reasoned, would produce lower shear and less breaking. At all speeds, the screw pump produced more breakage than did the centrifugal pumps. This was true even at low pressure-high flow conditions where the centrifugal pumps were satisfactory. The screw-type pump clearances are apparently such as to produce high shear even at slow rotation speeds, and pumps of this type are not recommended for either boost or fueling purposes.

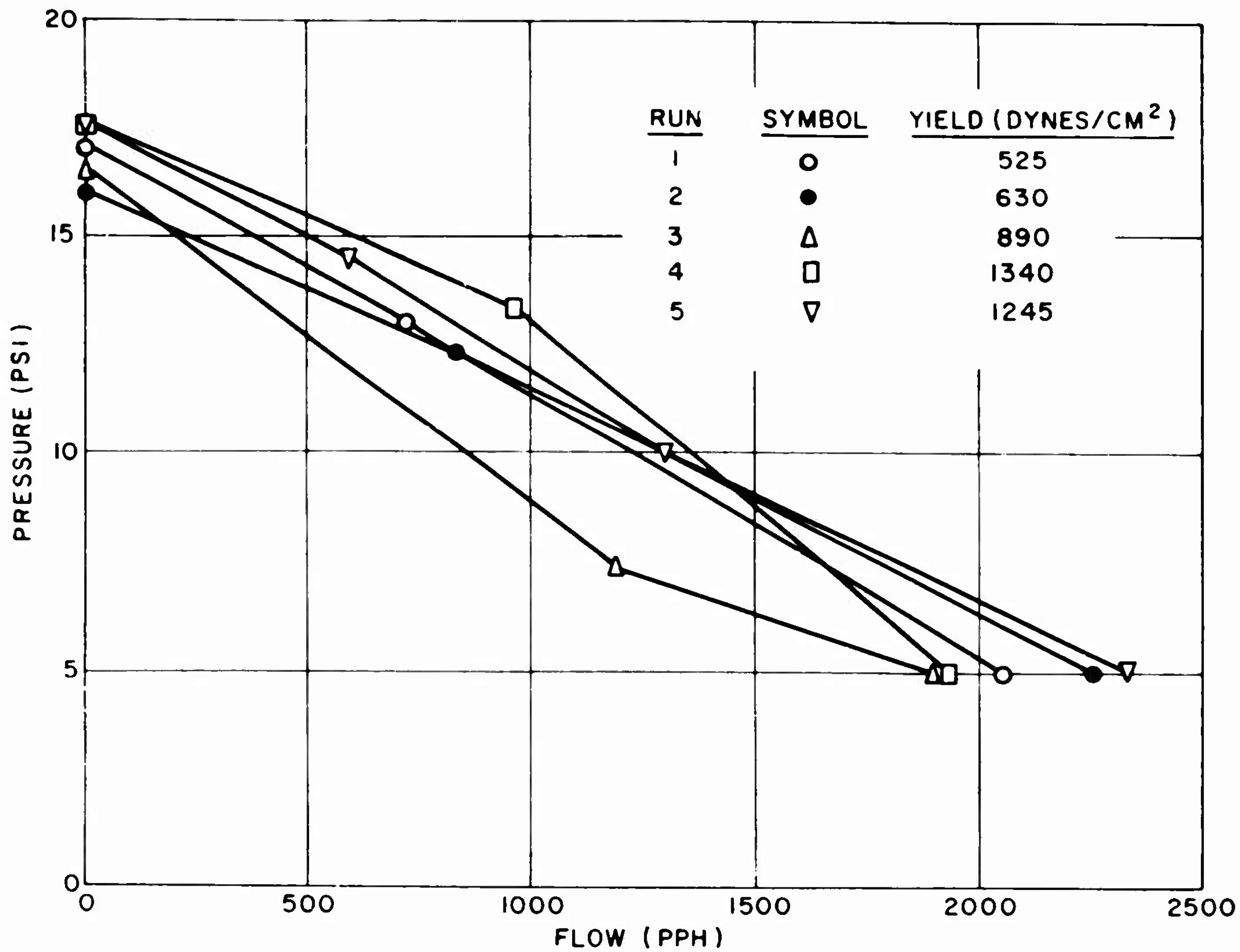

Figure 36. Flow vs Pressure Head, Boost Pump A, Emulsion A at Different Yield Values.

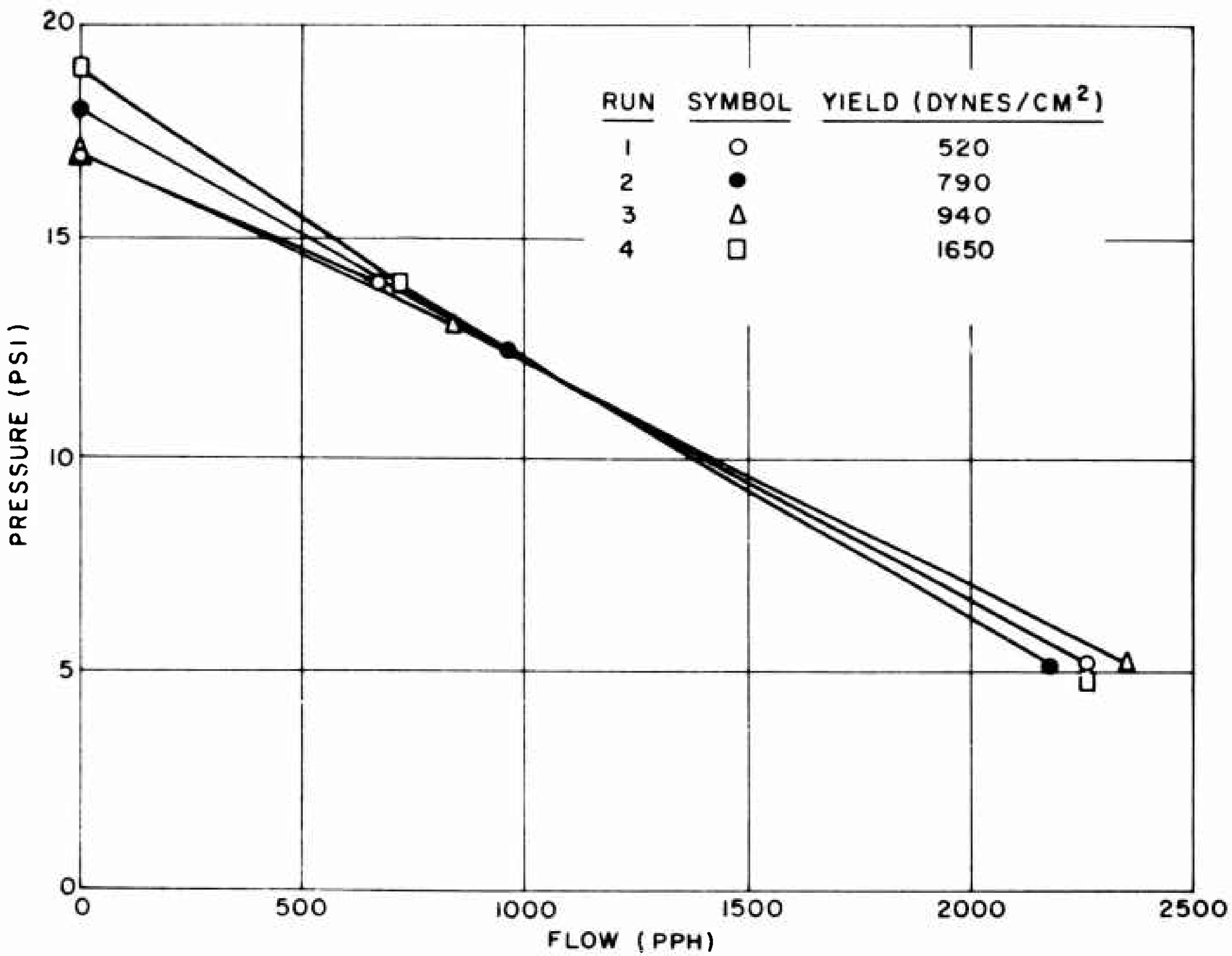

Figure 37. Flow vs Pressure Head, Boost Pump B, Emulsion A at Different Yield Values.

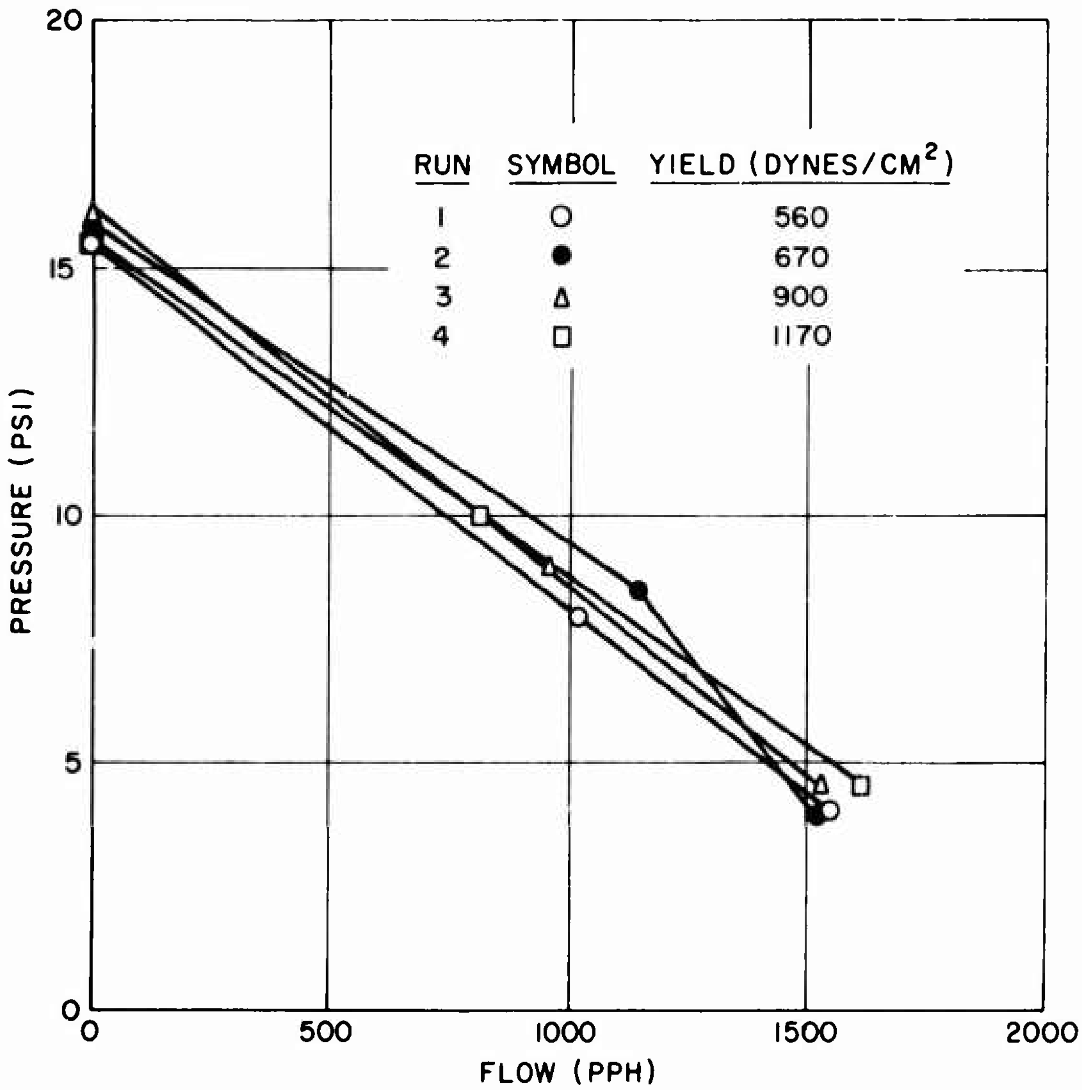

Figure 38. Flow vs Pressure Head, Boost Pump D, Emulsion A at Different Yield Values.

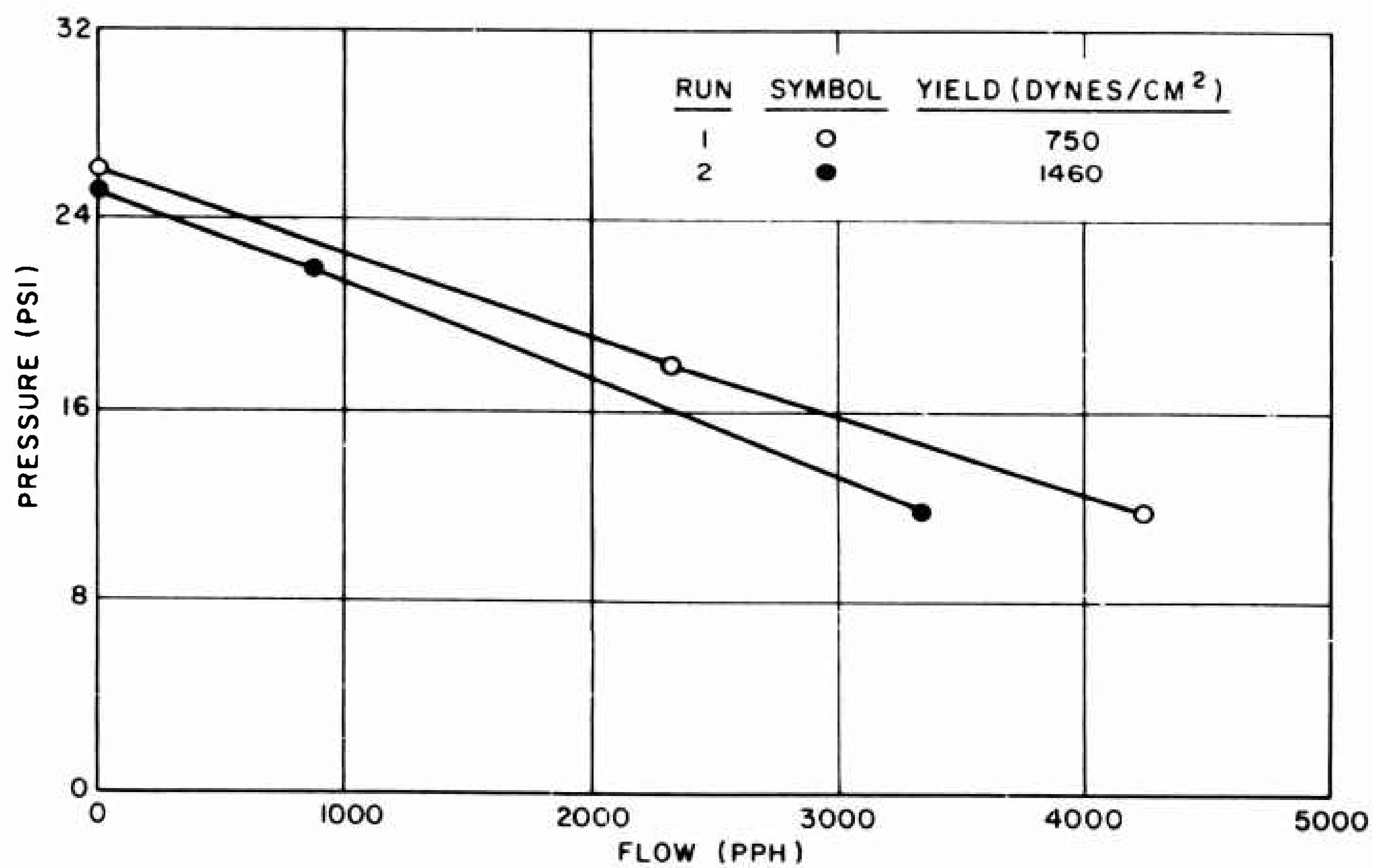

Figure 39. Flow vs Pressure Head, Boost Pump E, Emulsion A at Different Yield Values.

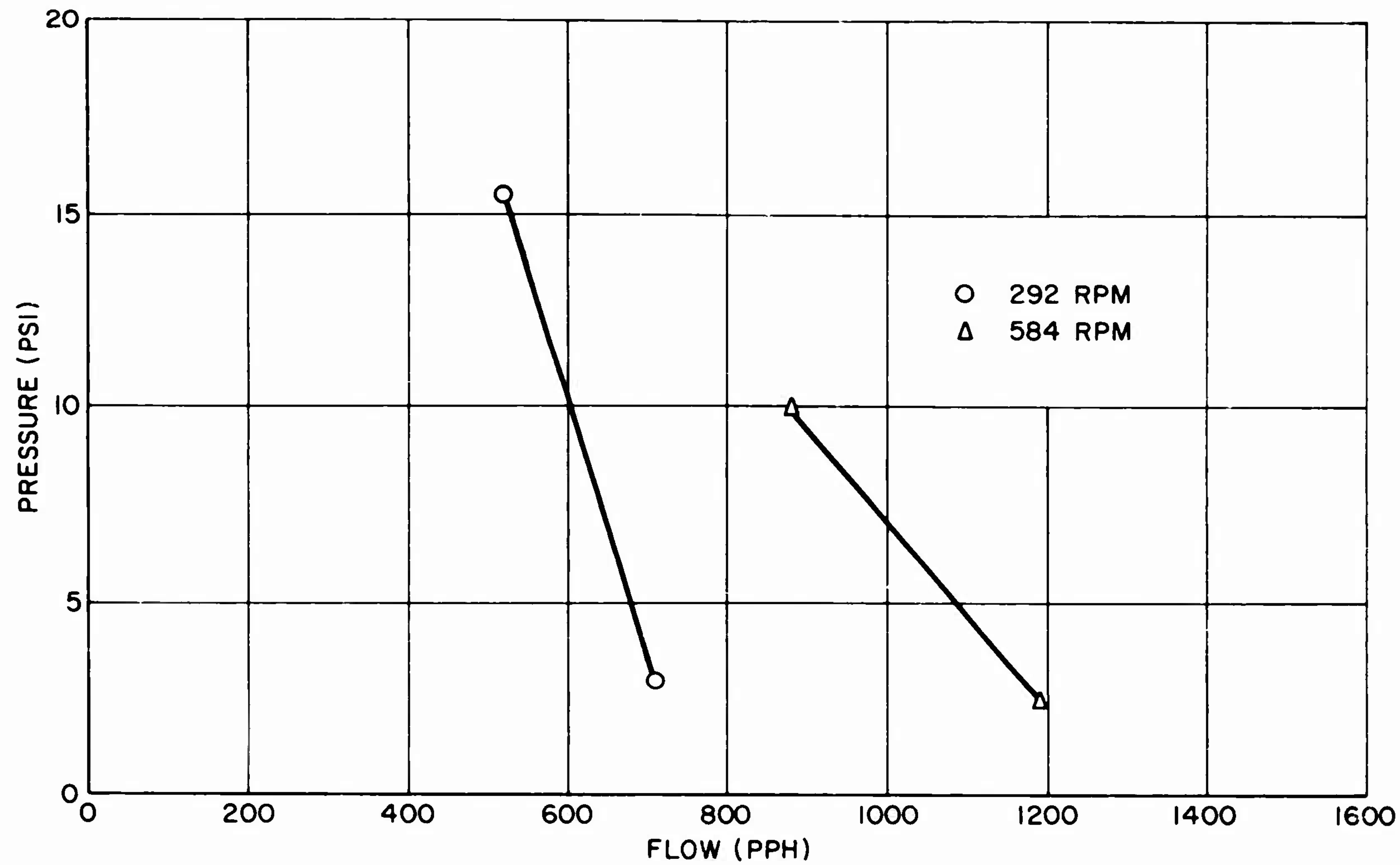

Figure 40. Flow vs Pressure Head, Screw-Type Pump, Emulsion A, Relaxed State.

FUEL FILTERING AND DECONTAMINATION

SELECTION OF METHODS

The removal of particulate material from the emulsified JP-4 fuels was expected to be difficult because of the apparent viscosity and yield value of the emulsions. Ordinary depth filtration of the type in use was expected to give excessive pressure drops, and centrifugation was expected to be inefficient because of the drag forces exerted by the emulsions on the particles being centrifuged. Edge-type filtration was expected to give better results down to some specific filter opening, and then excessive pressure drop would rule out further decrease in opening size.

CONTAMINATION TESTS

Particle counts were made on the three emulsions to determine the approximate amounts of contaminants present in different size ranges. Counts were made on 100 ml samples of emulsion which were broken prior to filtration by the addition of filtered isopropyl alcohol. Standard 0.45-micron membrane filters would not transmit the broken emulsions, and cellulose milk filter pads were used instead. For this reason the particle counts in the 10- to 25- micron size range are questionable. Typical counts are:

	Emulsion		
	A	B	C
10-25μ particles/100 ml	473	937	330
25-50μ particles/100 ml	547	742	466
50-100μ particles/100 ml	272	393	241
>100μ particles/100 ml	79	58	169

The bulk of the contaminant consisted of amber flakes from the internal coating of the shipping drums and black fibrous material which appeared to be from hoses. Some metal particles were present and were largely steel chips except for the case of one welding spall.

CENTRIFUGATION

Tests performed on the emulsions, using centrifugation for removal of particulates, gave no appreciable contaminant removal in periods less than 5 minutes. The time period involved would indicate that an aircraft on-board unit would have to be of very large size to give an equivalent exposure to the "g" field.

DEPTH FILTRATION

Standard depth-type filter media were found to have pressure drops in excess of 20 psi without allowing emulsion flow.

EDGE FILTRATION

Examination of edge-type filter media, in this case stainless steel screens, was carried out using the apparatus shown in Figure 41. Screens having 1.75-inch area and various mesh sizes and openings were tested with the three emulsions to determine flow rate as a function of pressure drop across the screens. The results of the tests are shown in Figures 42, 43, and 44. Pressure drops are acceptable up to the 120 mesh, .0046-inch opening size screens, and Emulsion B shows better flow properties than do Emulsions A and C. The 400-mesh screens produced partial emulsion breakage with all three emulsions, and there is some indication that Emulsion A was breaking slightly with the 120-mesh screen. This is indicated by the closeness of the curves for the 60-mesh screen and the 120-mesh screen. Some difficulty was encountered with Emulsion B. This resulted from the inability to force Emulsion B through the lines at low flows. The material would flow momentarily, stop, and then flow again, making it difficult to obtain data. At higher flow rates this did not occur, but there were signs of emulsion breaking (about 30 percent fluid present). A considerable quantity of coarse solid contaminant was removed from Emulsion B by the 120-mesh screen. The 120-mesh screen represents the lowest screen limit for filtration if emulsion breaking and high pressure drops are to be avoided.

MESH FILTER EVALUATION

Additional work was carried out using a 120-mesh screen filter made up in the same configuration as present depth-type units. The test filter and housing are shown in Figure 45. The filter bypass was blocked closed for the test. Only Emulsion A was used in the test, but it was used both in the as-received state and with an increased yield brought about by mechanical working. The test results are shown in Figure 46. Based on the curves of flow and pressure drop for a 1.75-square-inch screen, higher flows were expected for the as-received material at equivalent pressure drops for the larger area filter. This did not occur, and, in fact, higher pressure drops were found. One possible explanation is that, with the smaller area, shearing forces brought about enough emulsion breakage for the interior phase to act as a lubricant; this did not occur with the larger area filter. The thickened emulsion gave results just opposite to expectations. The pressure drops through the filter are considerably lower than for the as-received emulsion and at high flows approximate the pressure drops for the thickened emulsion and the housing.

A 120-mesh screen with .0046-inch openings is roughly equivalent to a 115-micron filter. Filtration at this level will be satisfactory for the engine-driven fuel pump if the pump wearing surfaces are hard and the particulate material is soft. From the samples of the emulsions which were examined microscopically for contamination counts, the majority of the metal present was larger than 115 microns. The 120-mesh filter would then be the largest permissible size. A second

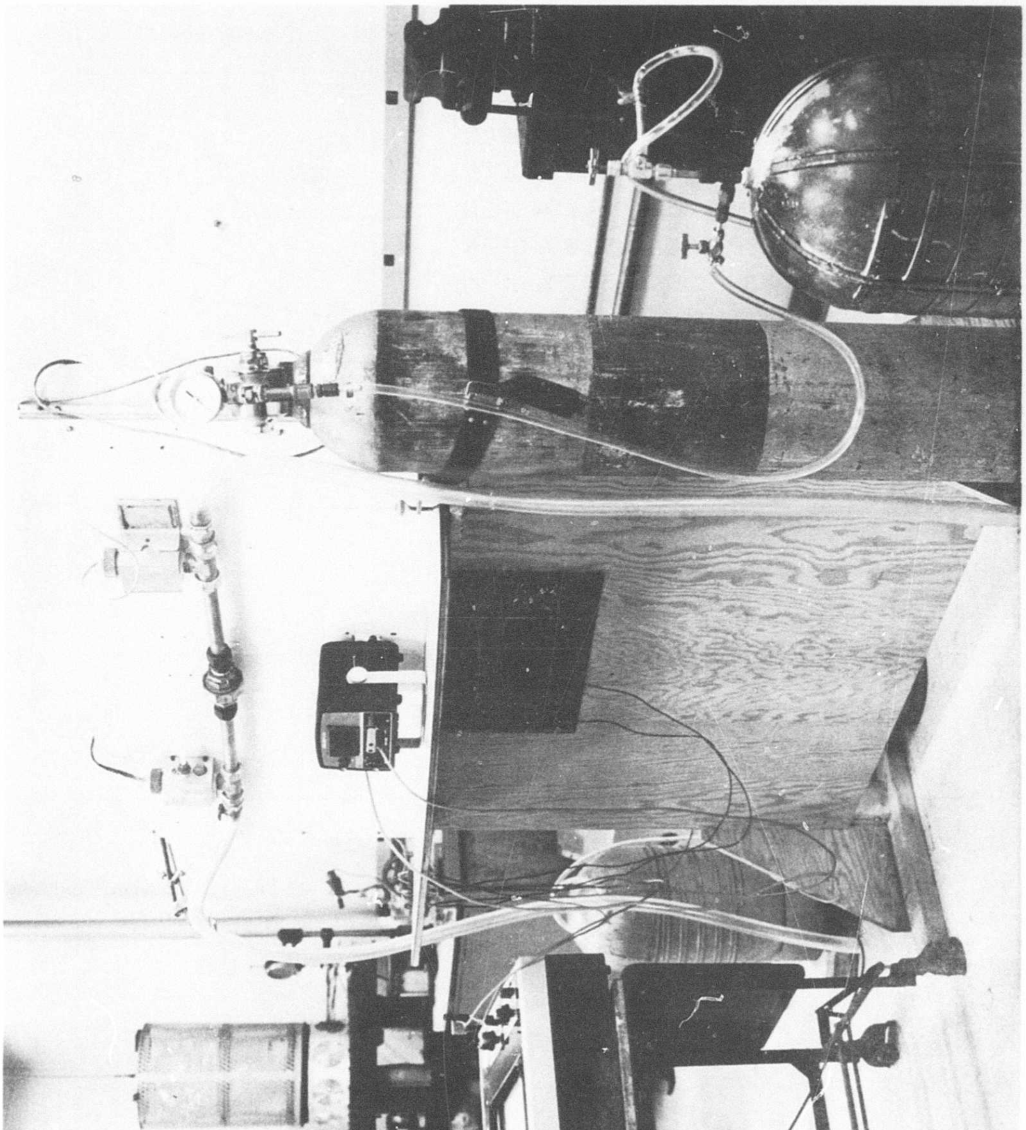

Figure 41. Filter Test Apparatus.

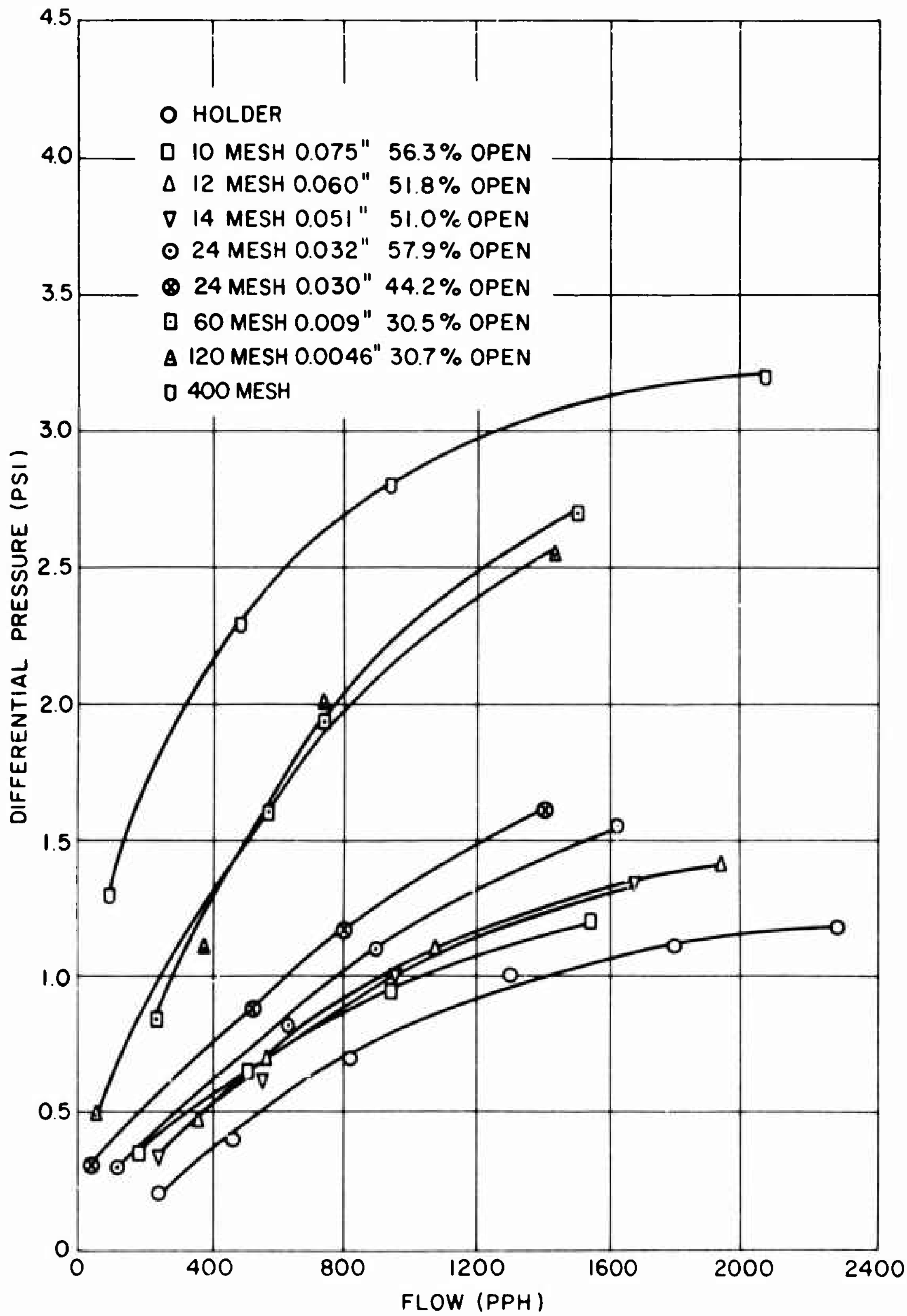

Figure 42. Flow vs Differential Pressure, Emulsion A, 1.75 in.^{2} Area Screens.

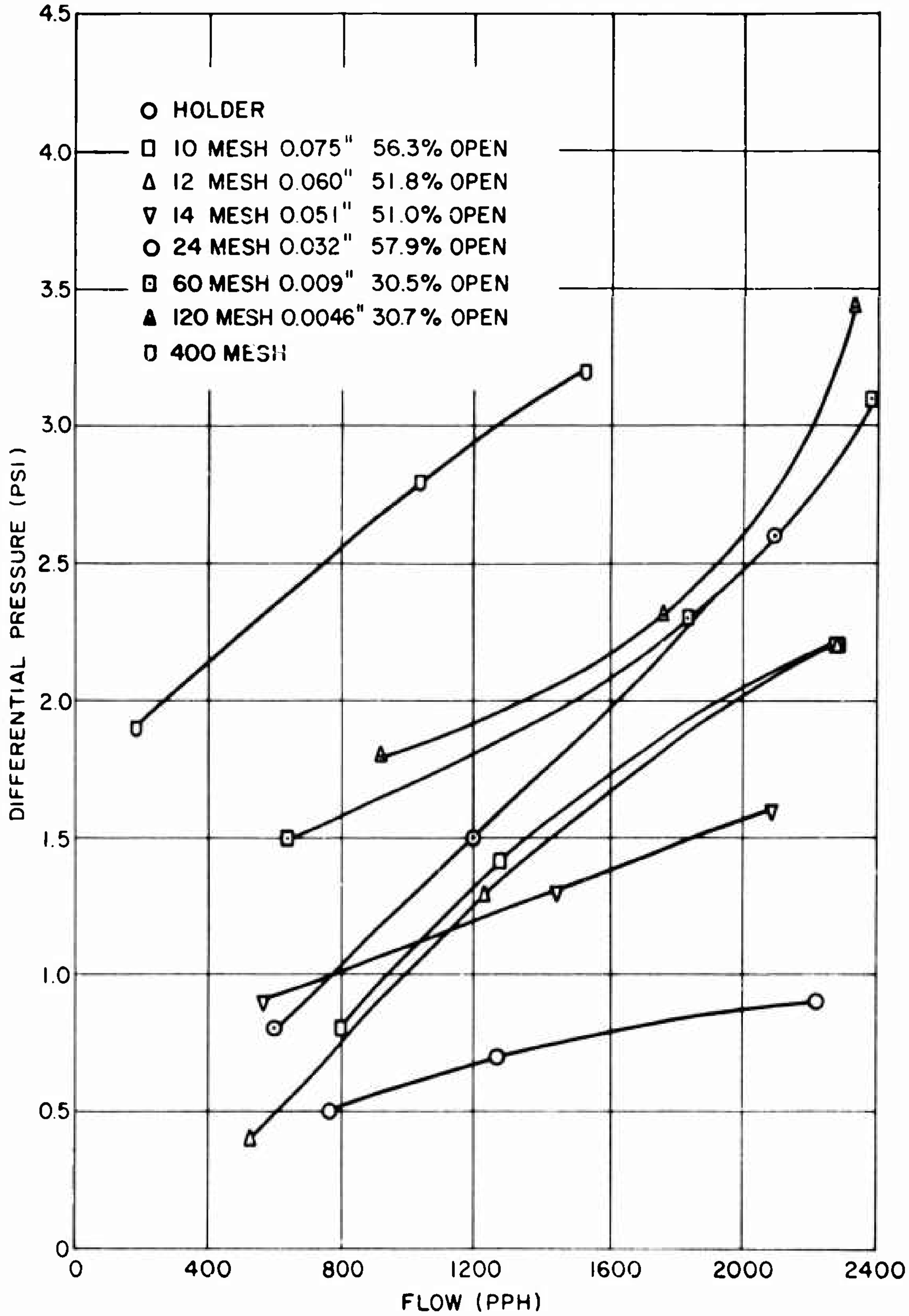

Figure 43. Flow vs Differential Pressure, Emulsion B, 1.75 in.^{2} Area Screens.

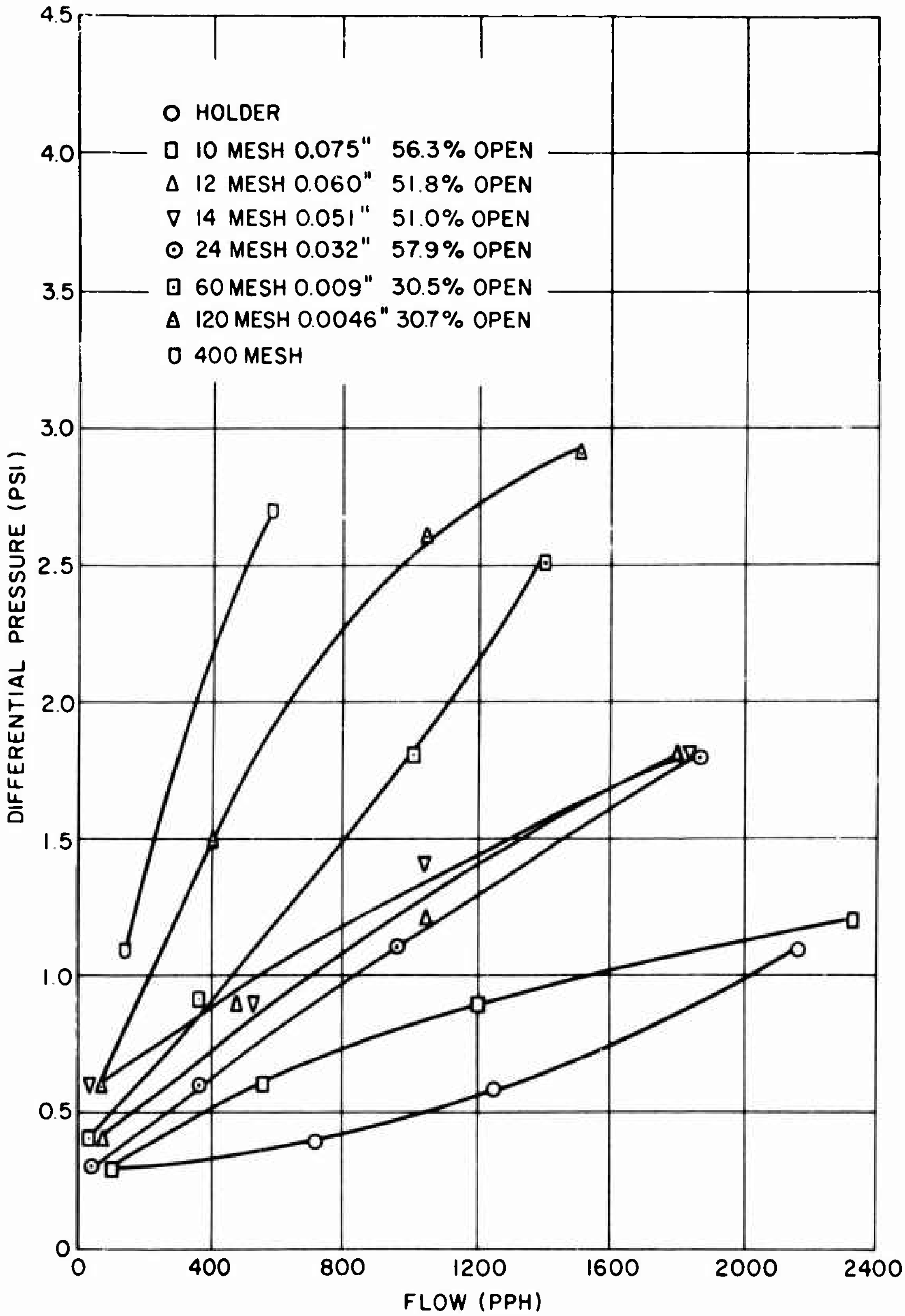

Figure 44. Flow vs Differential Pressure, Emulsion C, 1.75 in.^{2} Area Screens.

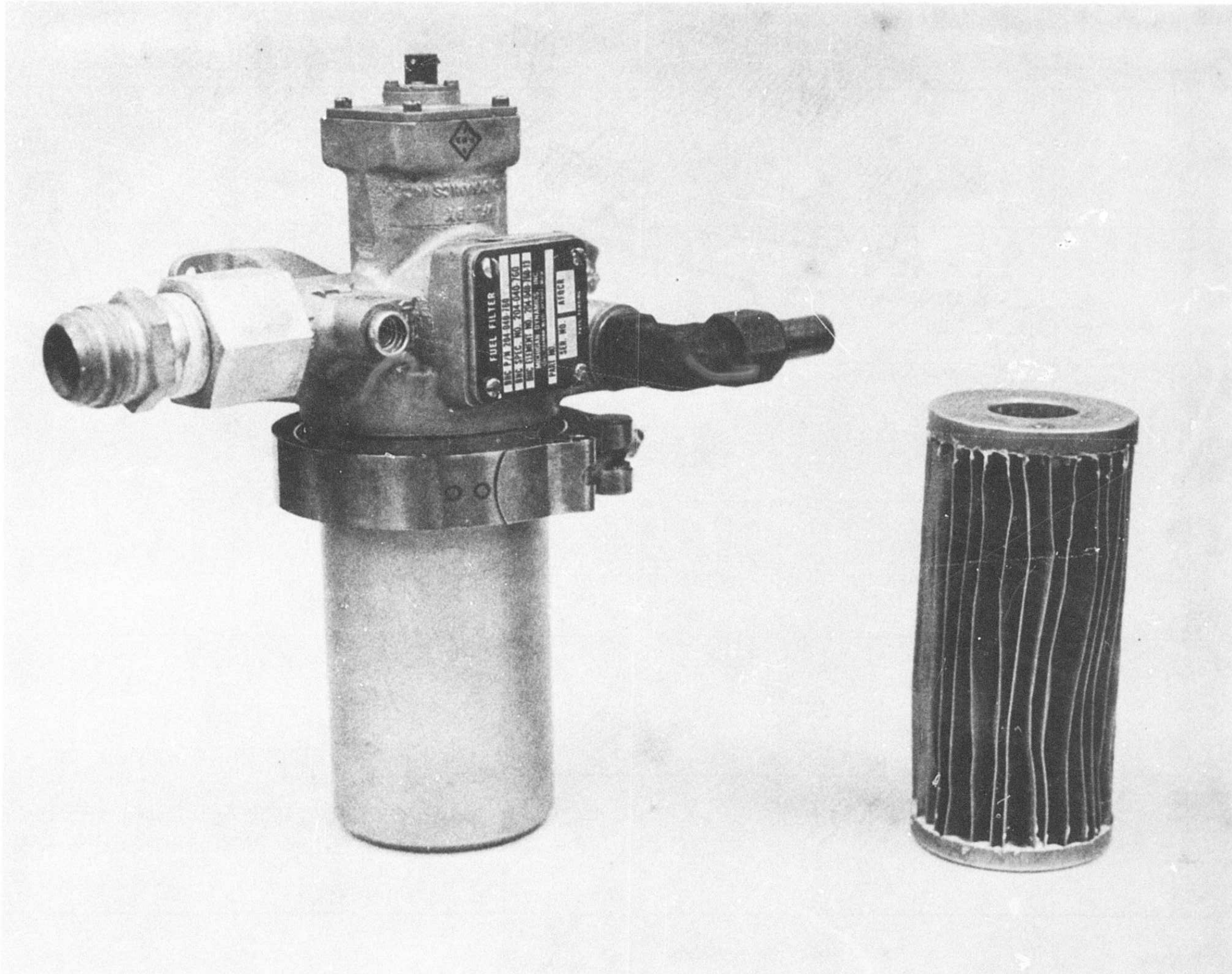

Figure 45. Test Filter and Housing.

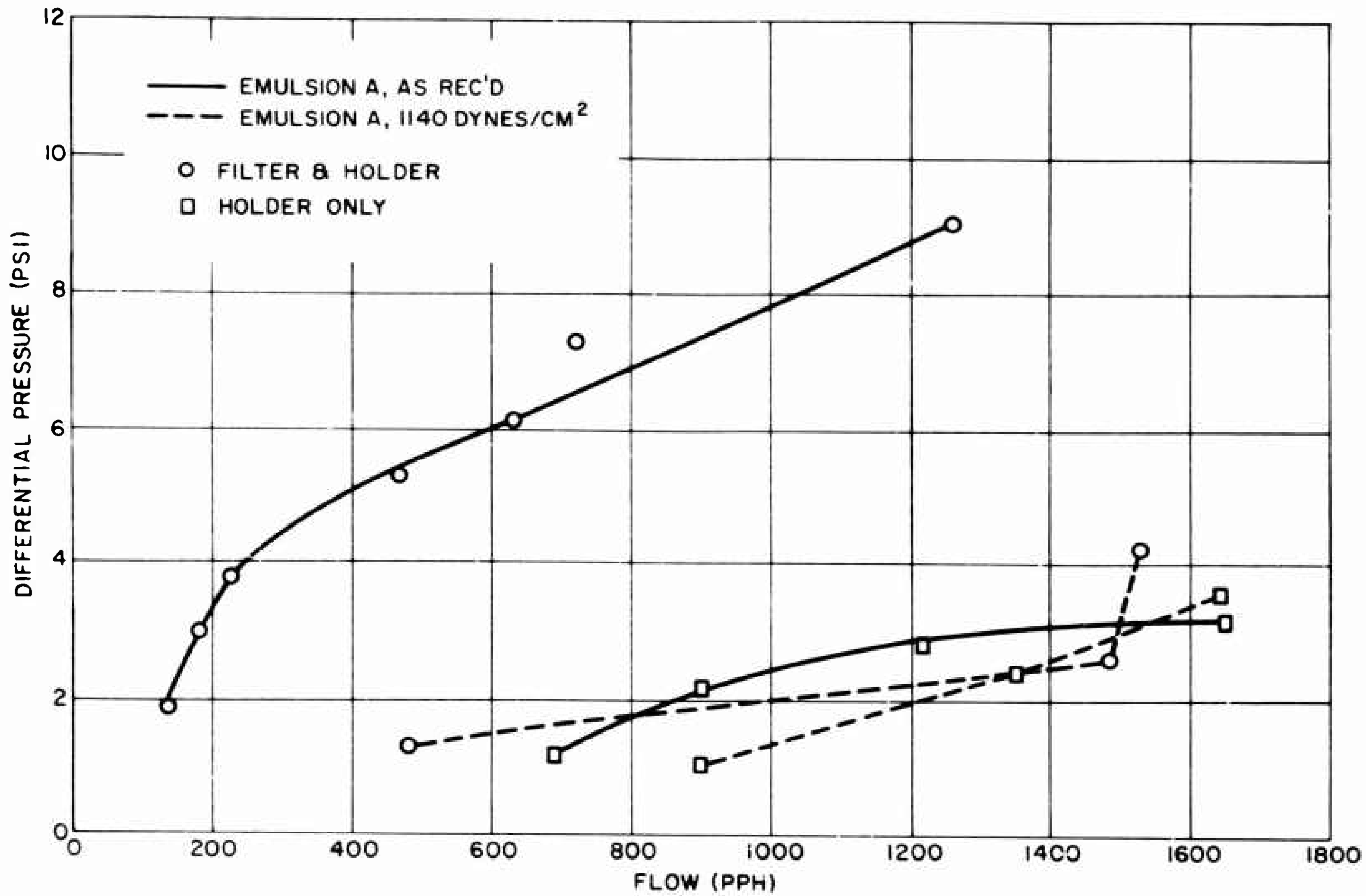

Figure 46. Flow vs Differential Pressure, 120-Mesh Filter and Housing.

fine filter of 10- to 20-micron size which can use the pressure of the engine-driven fuel pump would be required to protect the fuel control valve and engine nozzles from contamination.

Considerable attention should be given to clean manufacturing, packaging, and transfer of the emulsions to reduce the likelihood of contamination damage to the engine-driven pump from contaminants in the less than 115-micron size region.

The degree to which material not removed by 115-micron filtration will affect engine-driven pump performance should be ascertained, and effort should be directed toward fine filtration of the emulsion between the engine-driven pump and the fuel control valve. To avoid high pressure drops,demulsification may be required before the fine filtration.

FUEL QUANTITY MEASUREMENT

SELECTION OF METHODS

It was anticipated that present capacitance-type fuel gauges would not function properly with emulsified JP-4 fuels primarily because of the electrical conductivity of the emulsions. In addition, the emulsions might adhere to the plates of the probe, form a bridge between the plates, and cause the probe to indicate a constant fuel level or to indicate a level which would be more than that actually present.

If conductivity of the emulsions represented a problem, then measuring the resistance of the fuel between two parallel, equal-area electrodes spaced far enough apart to prevent emulsion bridging of the electrodes would be a method to determine fuel height. The greater the quantity of fuel between the electrodes resulting from the fuel height in the tank, the lower would be the resistance between them.

An alternate method would use a capacitance measuring unit, but the plates of the probe would be coated with an insulating material. The effect would be to introduce a high capacitance which would then be varied by the amount of conductive emulsion between the plates of the probe.

RESISTANCE METHOD

The resistance method was tested using the apparatus shown in Figure 47. Two stainless steel, parallel strip electrodes of equal area were spaced 2.75 inches apart in an insulating frame, and the resistance between the electrodes was measured. The unit was placed in a 3-liter beaker, and emulsified fuel was measured into the beaker to a depth of 5 inches. The frame holding the electrodes was then withdrawn from the beaker by 1-inch increments, and the resistance was measured at each increment.

Figure 48 shows the results of the tests with the three emulsions. The resistance increase as the probe was withdrawn was the greatest with Emulsion A. Both Emulsions B and C showed smaller resistance changes over the full range and were more conductive than Emulsion A. The small resistance change shown by Emulsions B and C, together with the higher conductivity, indicates that the resistance measurement technique would be difficult to use with these emulsions. The technique could be used with Emulsion A. In all cases the emulsions did not adhere appreciably to the electrodes, and no bridging occurred.

INSULATED PROBE CAPACITANCE METHOD

For tests of the alternate method using an insulated capacitance probe, a commercially available unit of a type used in the petroleum and chemical industries was obtained. The unit consisted of a power supply giving 32 vdc, a readout milliammeter, a detection circuit, and a polytetrafluoroethylene coated probe with a tank mount. The probe length was 24 inches.

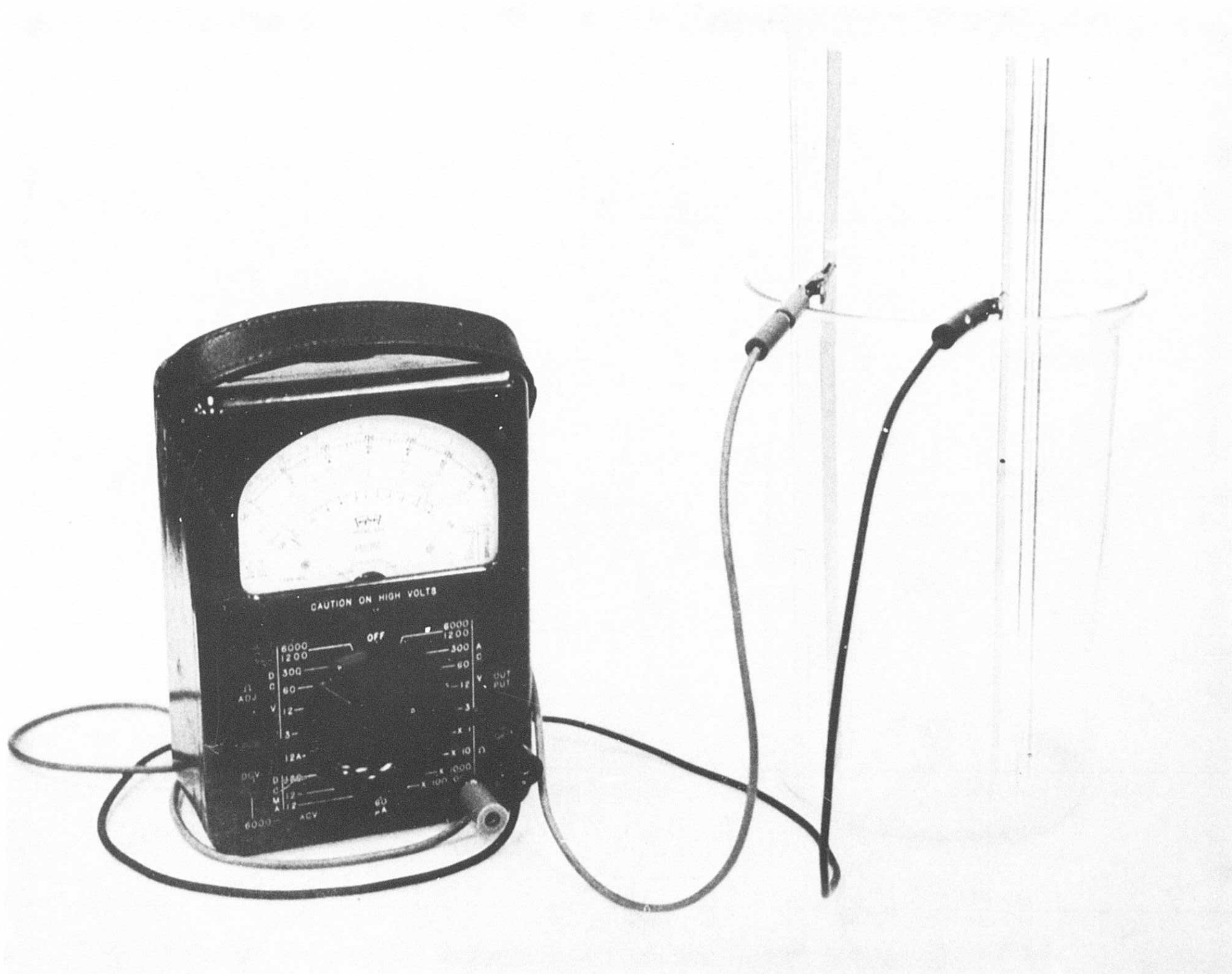

Figure 47. **Resistance Test Apparatus.**

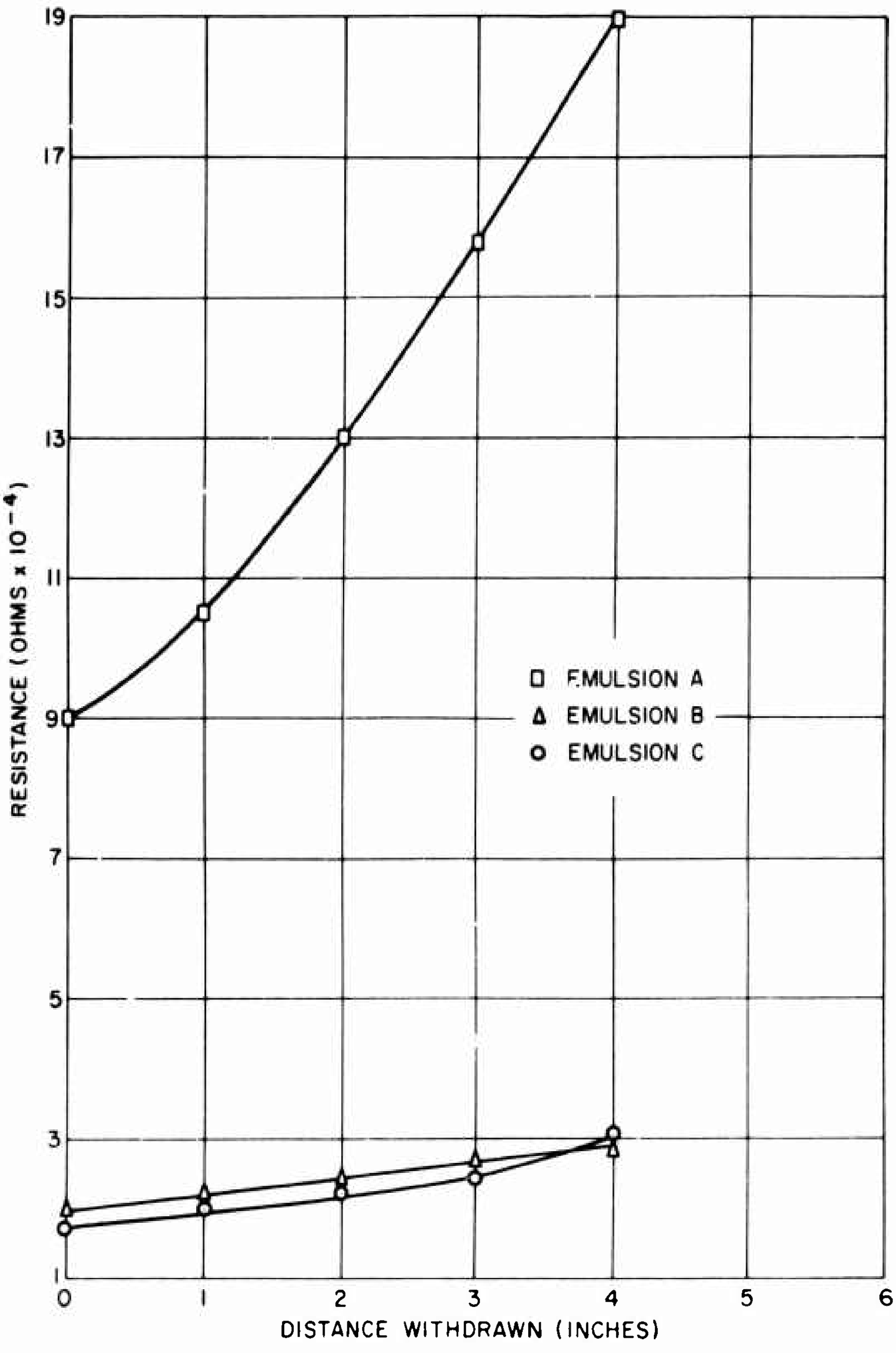

Figure 48. Resistance Readings for Various Electrode Immersion Depths.

The test system is shown schematically in Figure 49. The probe was placed in a cylindrical tank with a boost pump mounted to the tank bottom. After the system was calibrated to give meter readouts of zero percent for the empty tank and 100 percent for the tank filled with test emulsion, the emulsion was withdrawn by the boost pump. The distance of the fuel surface from the full reference mark was measured as a function of the meter reading in percentage of scale.

The results obtained for the three emulsions are shown in Figures 50, 51, and 52. Two runs were made for each emulsion to check the reproducibility of the readings. The full and empty points were calibrated only at the start of the first run for each emulsion. The reproducibility between runs for Emulsions A and C is acceptable for this type of gauge, but the results for Emulsion B show a 10 percent difference in the lower fuel level regions. The curves established for the three emulsions are not linear in that the indicated scale percentages do not correspond to the percentages of full volume. This difficulty should be easily overcome by correct proportioning of the meter scale divisions for the length of probe and emulsion used.

ADAPTATION

The most promising fuel level indicator for use with emulsified JP-4 is the insulated probe capacitance gauge. The unit which was tested could be easily modified for aircraft use. The following comments on the gauge components show the changes required:

1. Probe - No change required. Probe available in any length.

2. Probe tank mounting - Mounting must be modified to suit tank. The present mount is pipe threaded.

3. Detection unit - Present unit has miniaturized electronics but mounts in a heavy, armored housing attached to the probe mount. The unit should be combined with the readout meter.

4. Power supply - A transformer and rectifier circuit is used to give 32 vdc power from a 115 vac, 60 Hz source. Provision should be made to operate the unit directly from the aircraft dc supply.

5. Readout meter - The meter scale must be calibrated specifically for the emulsion to be used.

If the unit is adapted as indicated, the weight of the unit with a 24-inch probe but without connecting wire harnesses should not exceed 3 pounds.

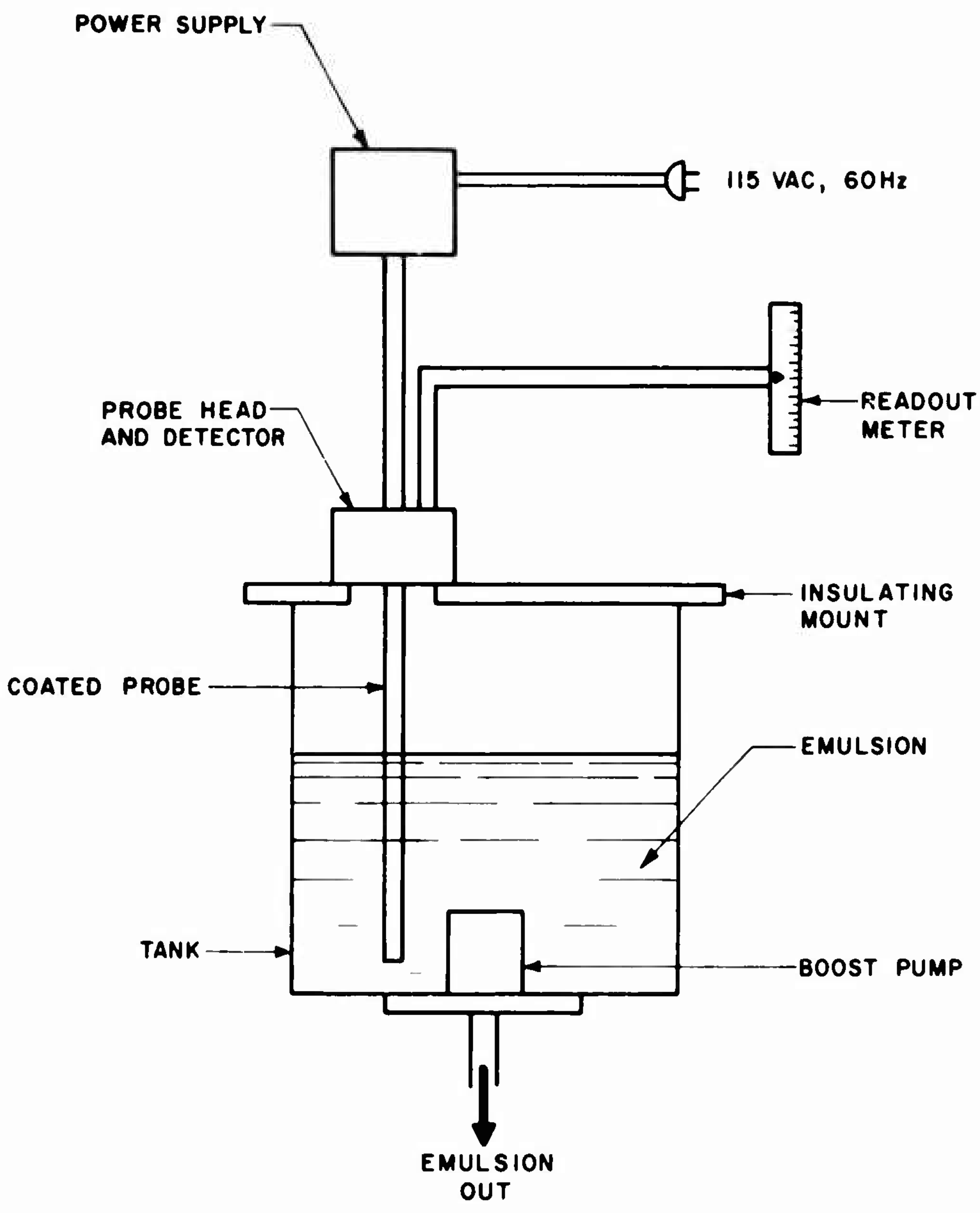

Figure 49. Capacitance Probe Test Apparatus.

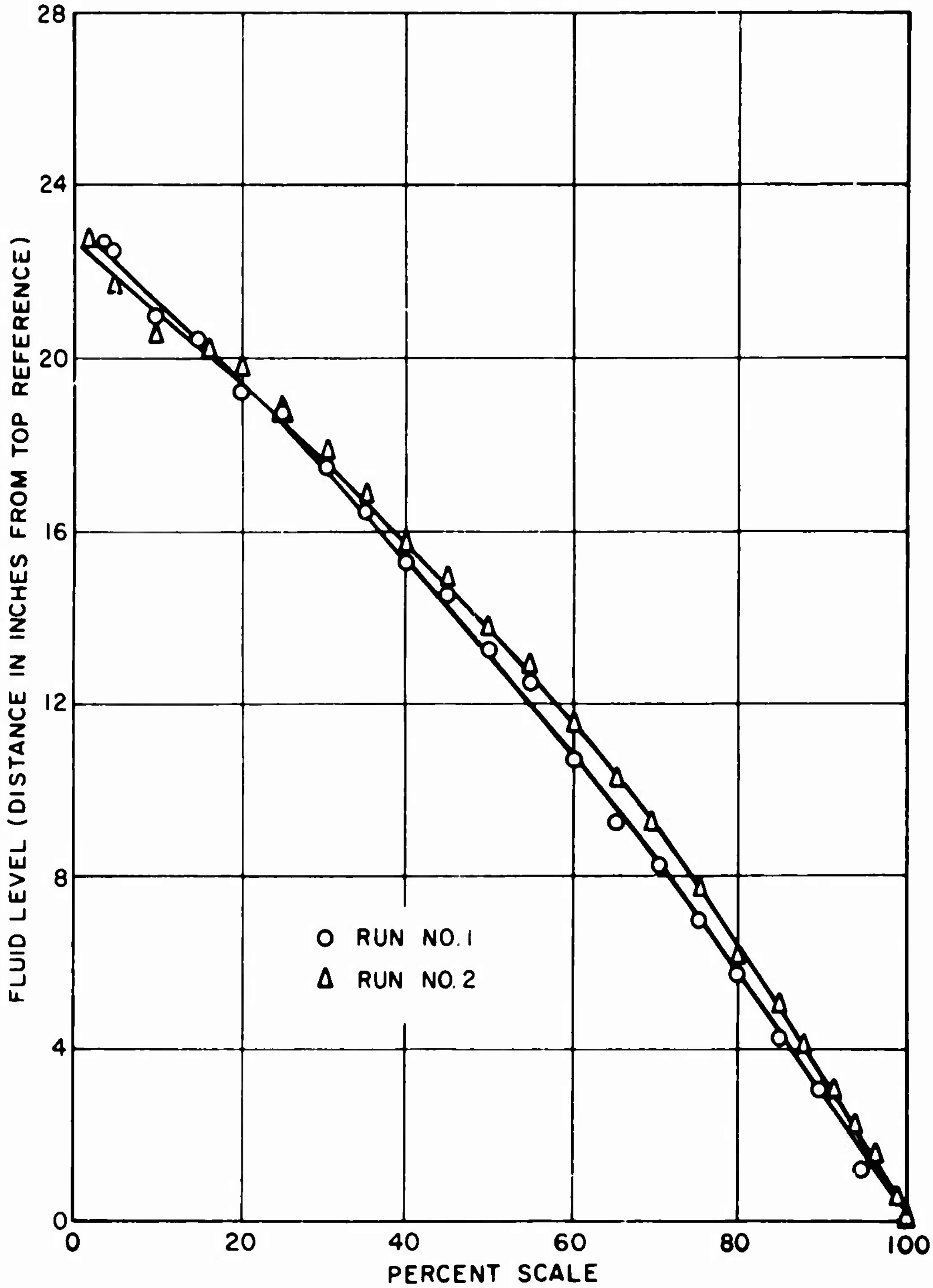

Figure 50. Fluid Level vs Scale Reading Capacitance Probe, Emulsion A.

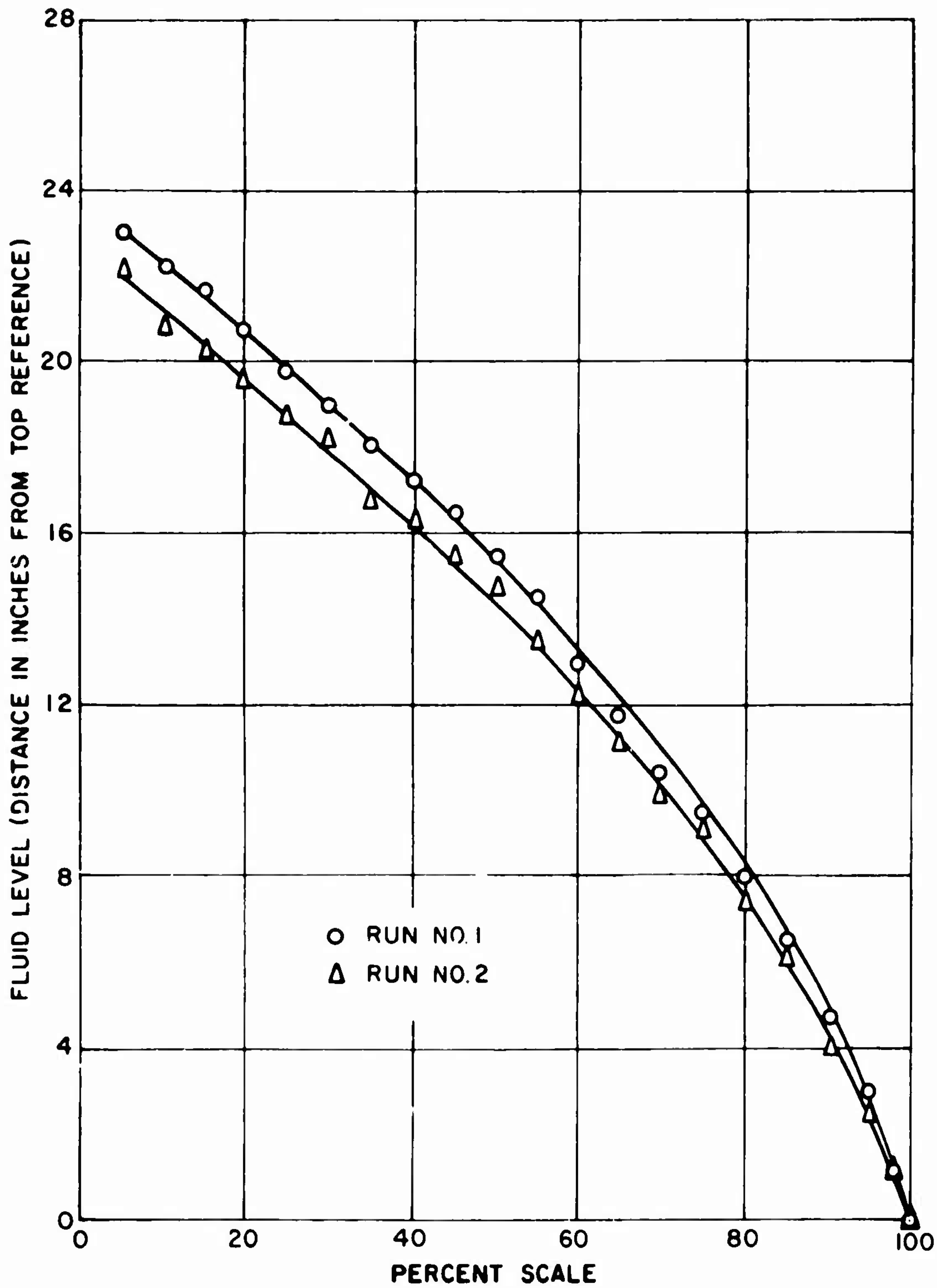

Figure 51. Fluid Level vs Scale Reading Capacitance Probe, Emulsion B.

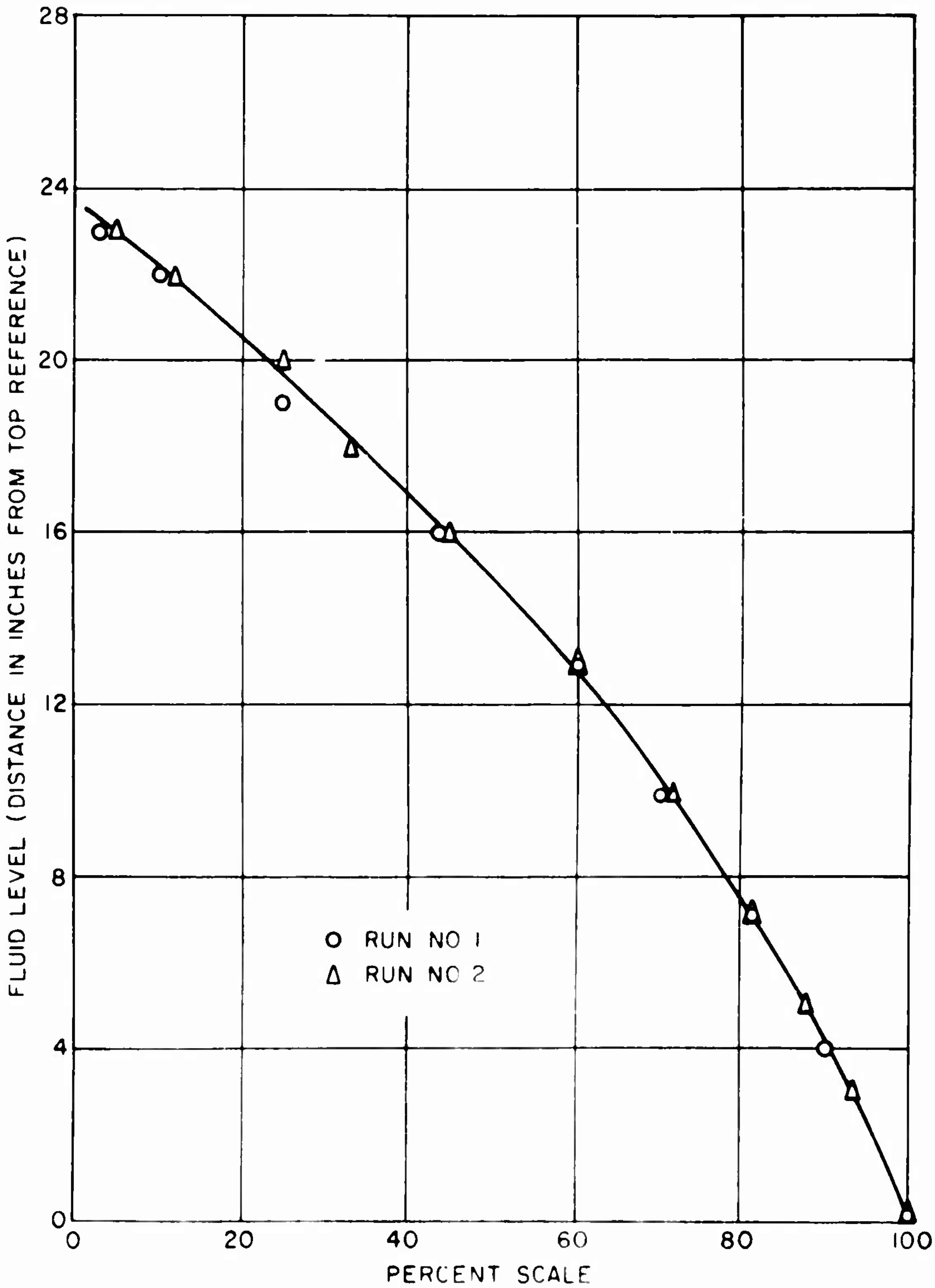

Figure 52. Fluid Level vs Scale Reading Capacitance Probe, Emulsion C.

FUEL TANK DESIGN

TANK LINING MATERIALS

A series of potential tank lining materials and three tank construction materials currently in use were tested for adhesion to emulsions by the method using a rotational viscometer as described in the section entitled Emulsion Behavior. Only Emulsions A and B could be evaluated, since Emulsion C failed to adhere to the viscometer cup. Increasing adhesion is indicated either by a decrease in strain rate at constant shearing stress or by an increase in shearing stress at constant strain rate. Under conditions of constant shearing stress, the time for the viscometer bob to turn a set number of degrees can be used to indicate adhesion. The time for revolution increases as the adhesion increases.

Adhesion of Emulsion A to four materials in order of decreasing adhesion is shown in Table I using strain rate at constant shear stress as the indicator.

TABLE I. RANKING OF ADHESION OF EMULSION A

Material	Strain Rate (sec^{-1})	Shear Stress ($dynes/cm^2$)
Polycarbonate	.051	270
Stainless Steel	.219	270
Polyethylene	1.877	270
Polytetrafluoroethylene	3.865	270

Adhesion of Emulsion B to the same four materials in order of decreasing adhesion is shown in Table II, but, this time, the shear stress at constant strain rate is used as the indicator. Polytetrafluoroethylene gave very high strain rates and must be compared to polyethylene at the same shearing stress.

TABLE II. RANKING OF ADHESION OF EMULSION B

Material	Strain Rate (sec^{-1})	Shear Stress ($dynes/cm^2$)
Stainless Steel	.0331	761
Polycarbonate	.0335	691
Polyethylene	.0310	208
Polytetrafluoroethylene	.580	208

For both emulsions, polytetrafluoroethylene gives the least adhesion, followed by polyethylene.

Present tank construction materials were evaluated with Emulsion A using the same technique; and stainless steel, polyethylene, and polytetrafluoroethylene were included as reference materials to check the results. The time for the viscometer bob to rotate 30 degrees is used as an indicator of adhesion. The materials are ranked in order of increasing adhesion in Table III.

TABLE III. RANKING OF ADHESION OF EMULSION A			
Material	Mass Required to Overcome Friction (grams)	Total Mass (grams)	Time to Rotate 30° (minutes)
Polytetrafluoroethylene	2.09	5.74	1.167
Polyethylene	1.83	5.74	1.985
Stainless Steel	3.27	5.74	4.835
Liner A, Side 1	2.37	5.74	10.835
Liner A, Side 2	2.76	5.74	14.885
Liner B, Smooth Side	1.57	5.74	25.300
Liner B, Rough Side	2.44	5.74	15.817
Liner C, Glossy Side	1.24	5.74	19.217
Liner C, Dull Side	1.50	5.74	27.350

The reference materials fall in the same order as noted previously,followed by Liner A material. Liner materials B and C are considerably worse than Liner A,but all of the presently used lining materials show much greater adhesion than polytetrafluoroethylene and polyethylene.

SUMPS

In pump test operations, it was noticed that emulsion had a tendency to hang up in the region between the tank wall and the back of the pump motor. This volume is blocked from the pump inlet by the motor and does not flow to the inlet because of the yield value. This condition is shown in Figure 53. By placing the pump in a sump at the tank bottom, approximately seven-eighths of the normal fuel hang-up was removed as shown in Figure 54. The sump, however, projects 10 inches below the tank bottom and would not be acceptable for present aircraft. The retention of fuel in the blind spot behind the pump inlet led to the tests of a 360-degree inlet described later in this section.

TANK OUTLET AND DIAMETER

Cylindrical tanks 2.5 feet in height and of different diameters were prepared for tests of tank length to diameter ratios. The tanks were mounted on a base having concentric grooves matching the diameters of the test tanks. Four hold-down clamps were used to clamp the desired tank size against a gasket contained in the appropriate groove. A pump mounting flange was provided in the base plate at the center of the concentric grooves. The test unit provided for rapid changeover from one tank size to another. The test unit with a 24-inch-diameter tank is shown in Figure 55. In operation, the tank assembly was weighed empty, full of emulsion, and after pumping the emulsion to the point where the pump took in air or, in the case of gravity drainage, to the point where drainage stopped.

Five different types of tank outlet-pump inlet configurations were used in the tests. Configuration 1 used only a brass adapter at the pump mounting flange, and flow from the tank was by gravity. Figure 56 shows this configuration.

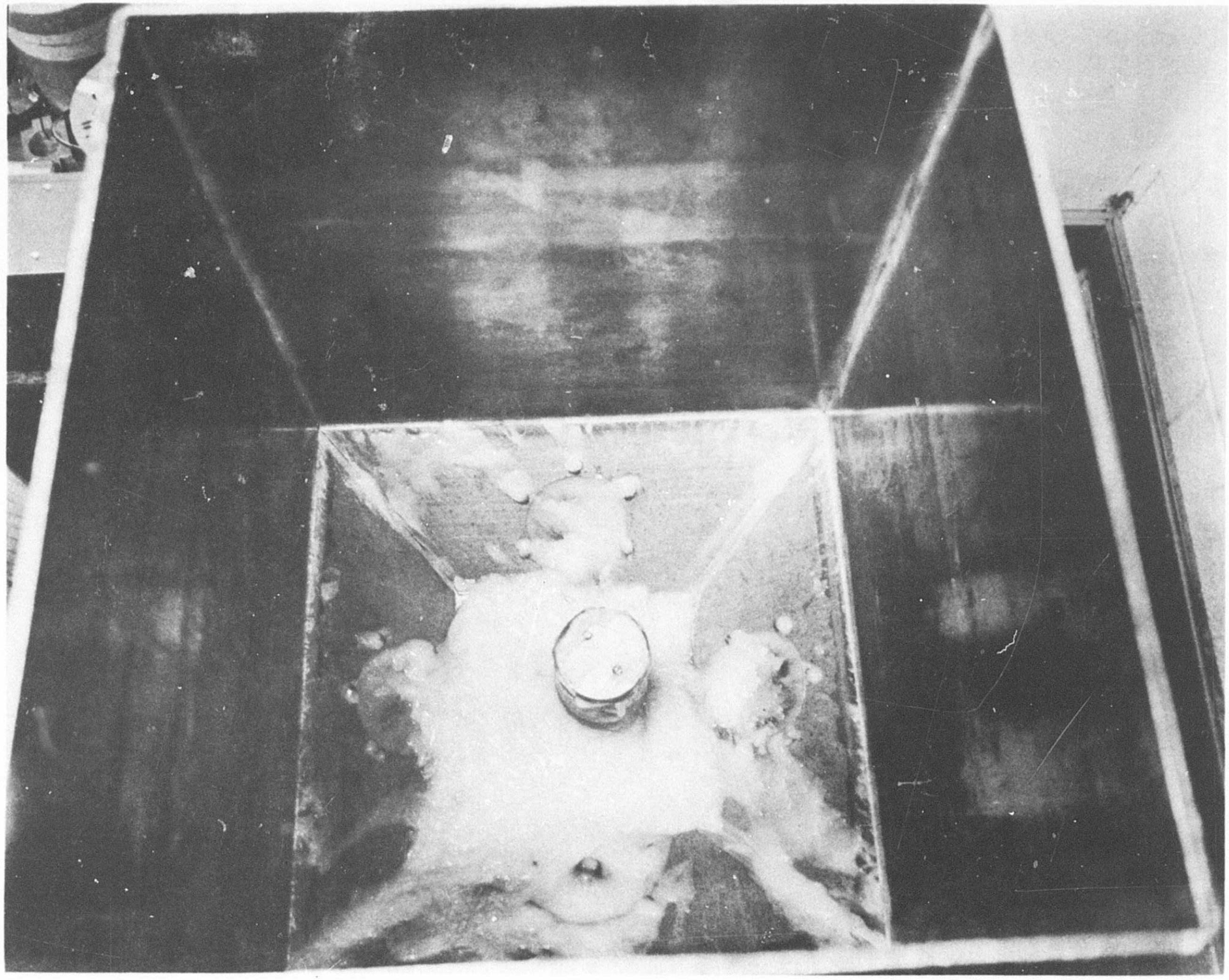

Figure 53. Tank Bottom Showing Fuel Hang-Up.

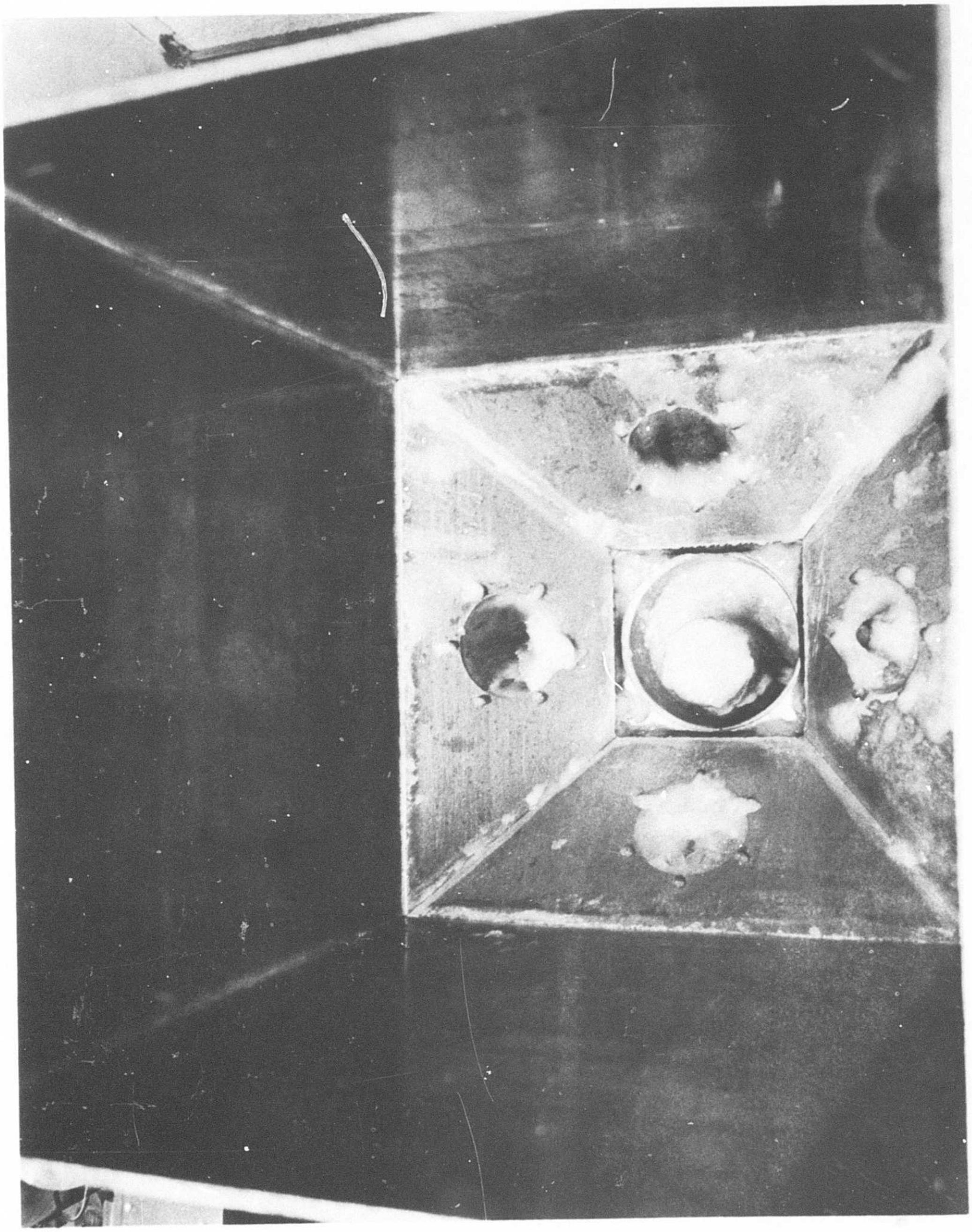

Figure 54. Tank Bottom With Sump.

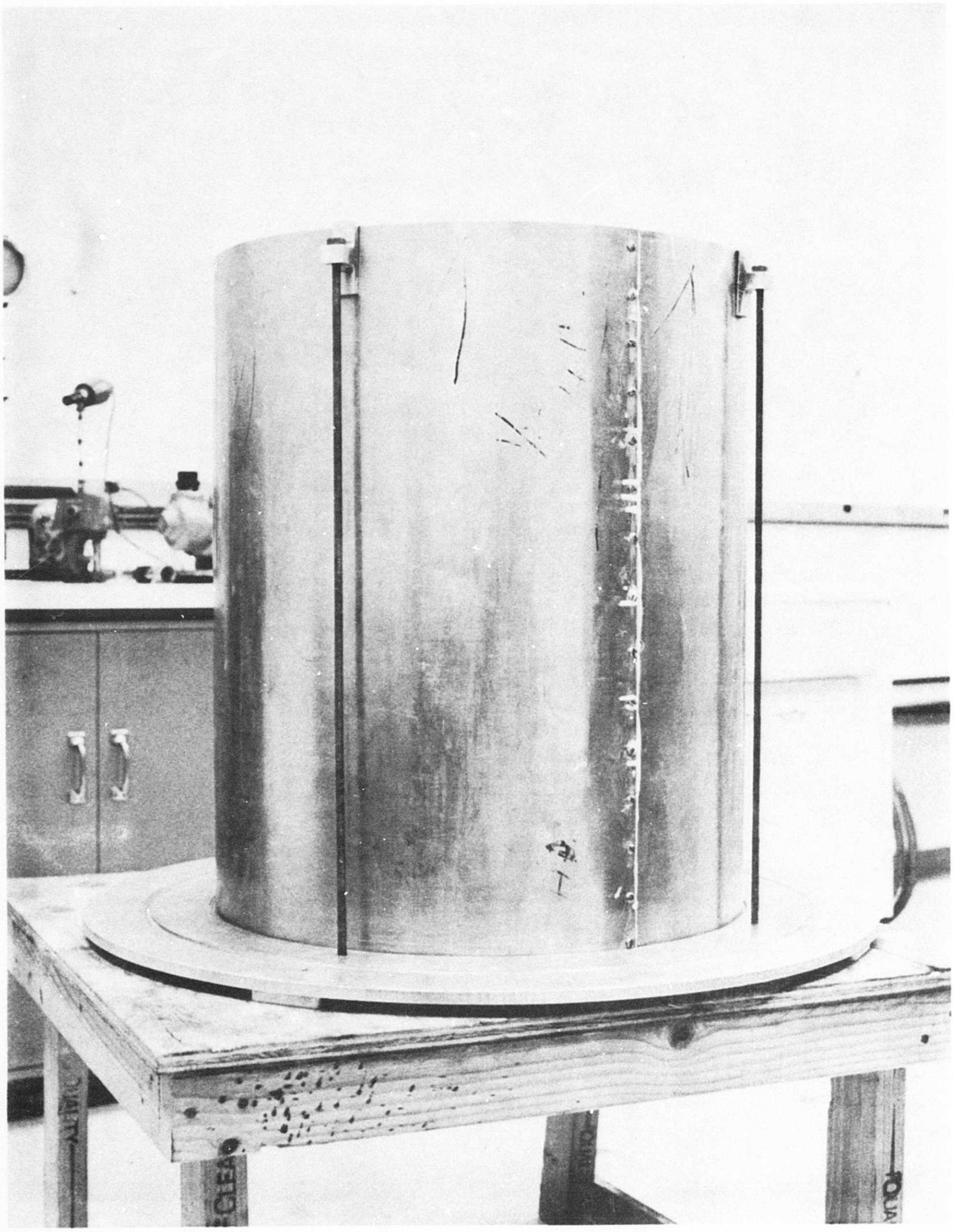

Figure 55. Tankage Design Test Unit.

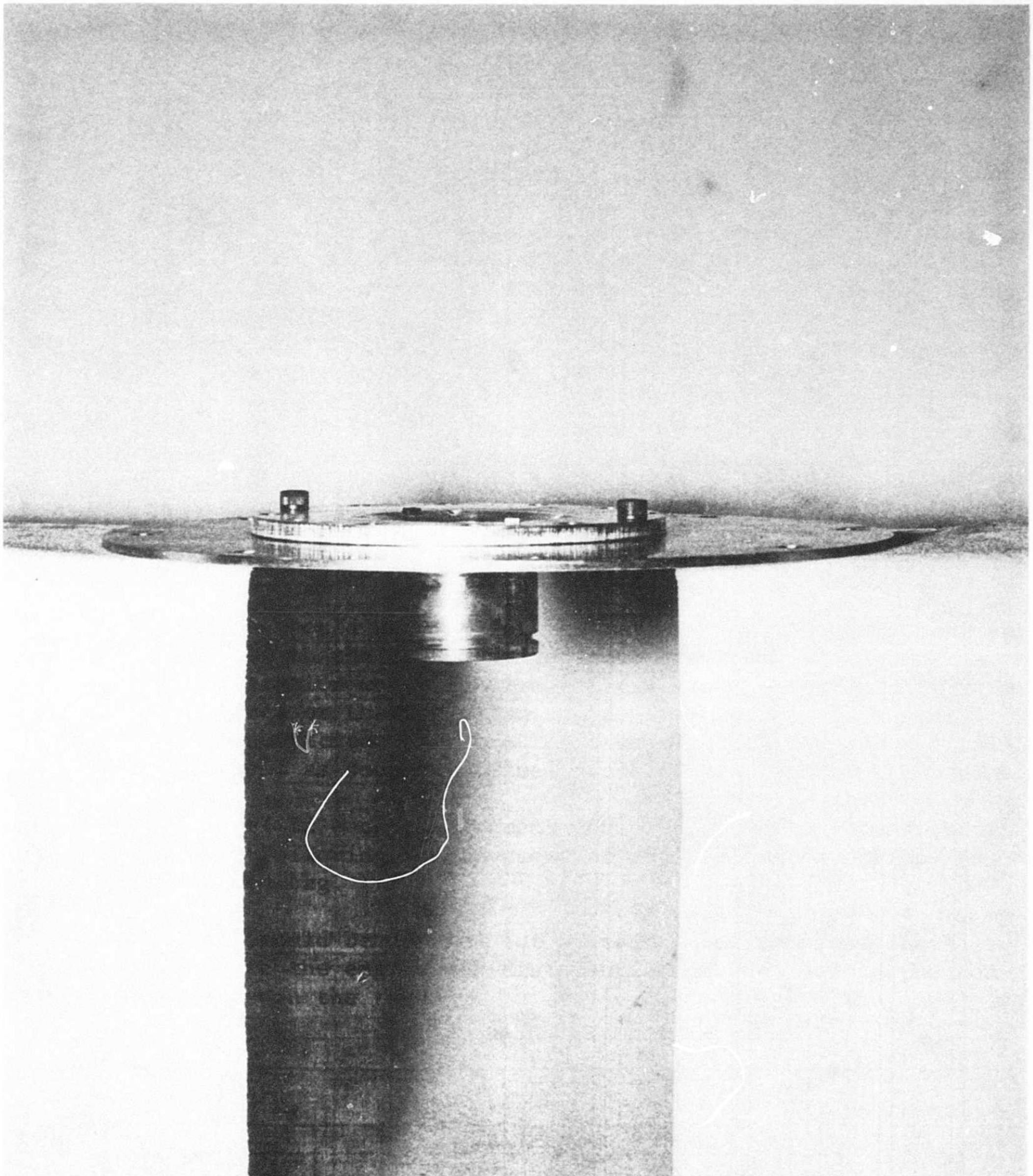

Figure 56. Outlet Configuration 1.

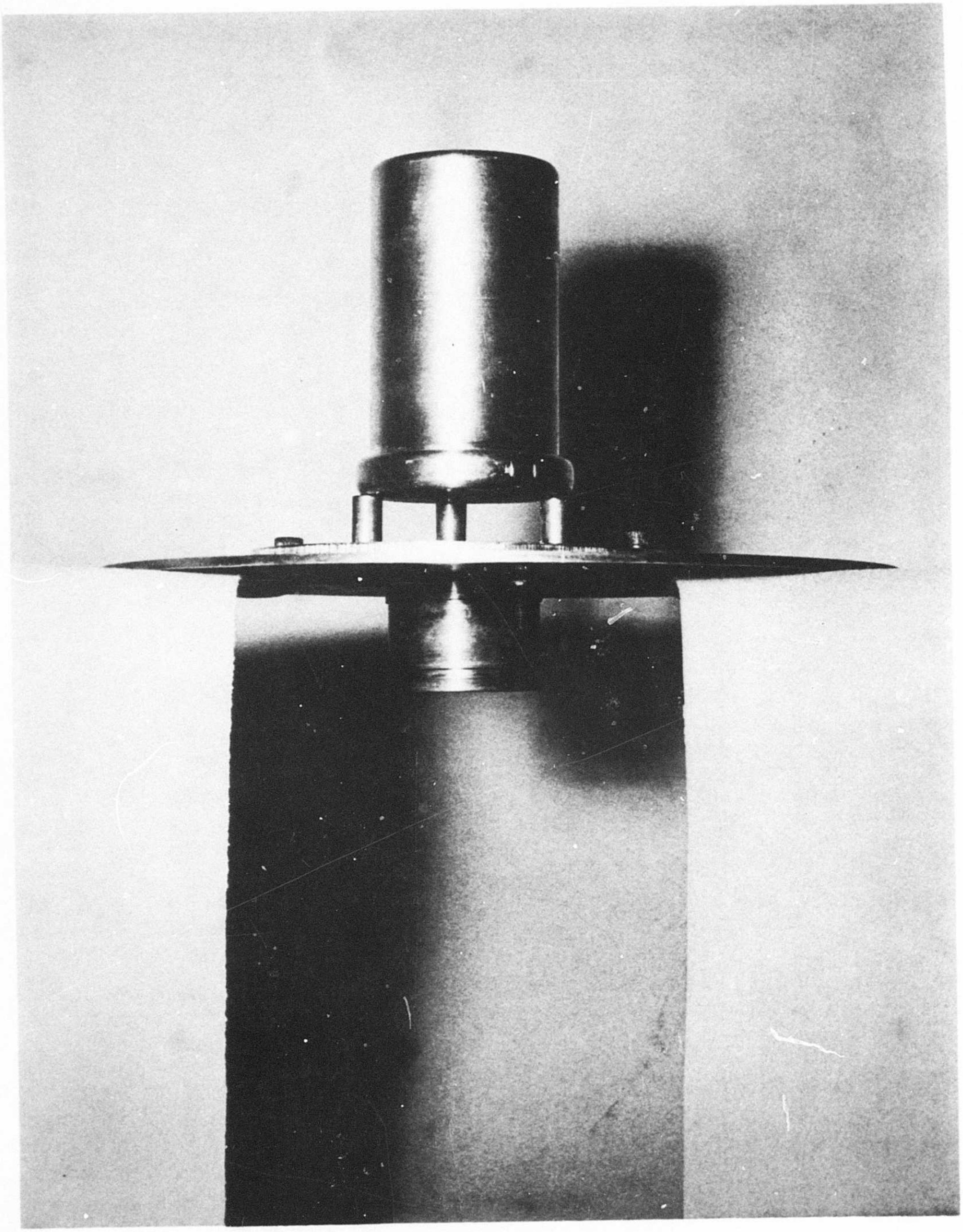

Figure 57. Outlet Configuration 2.

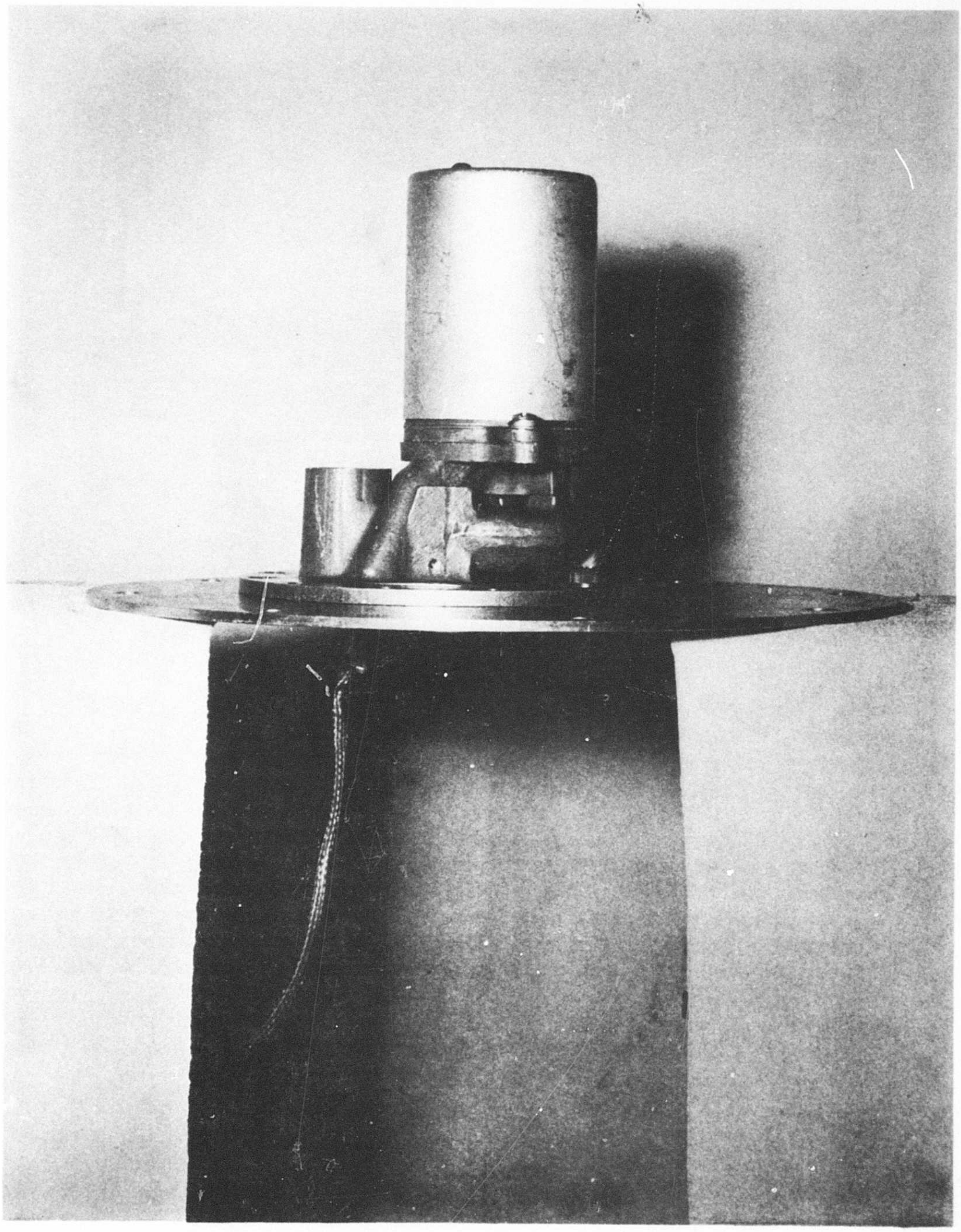

Figure 58. Outlet Configuration 3.

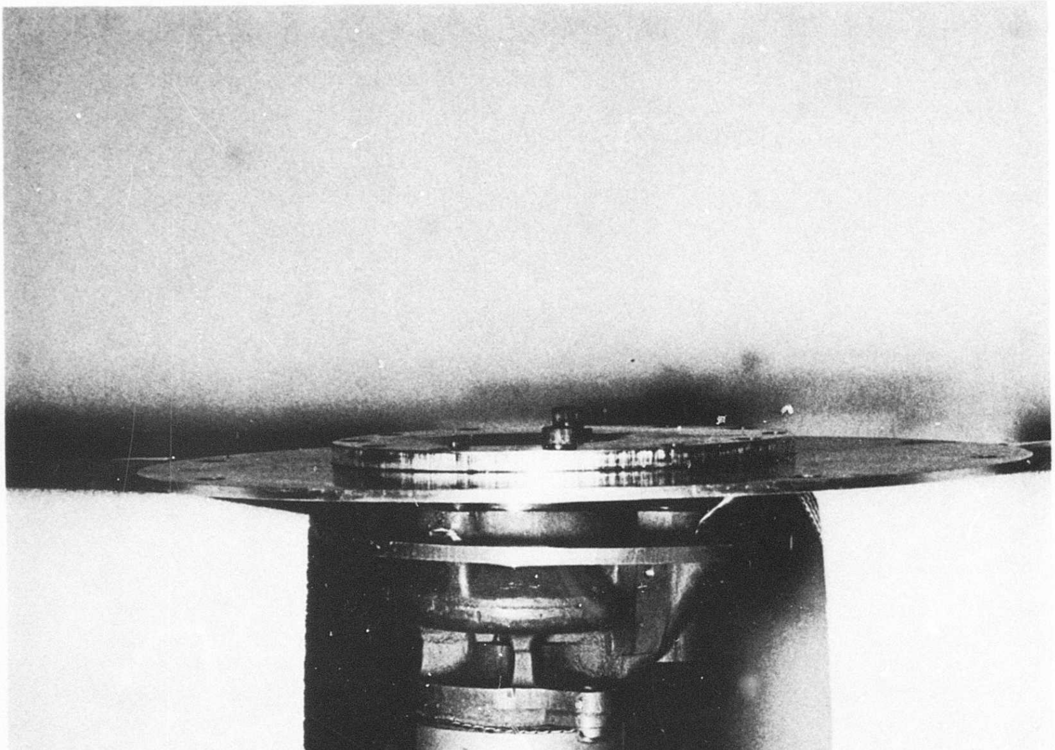

Figure 59. Outlet Configuration 4.

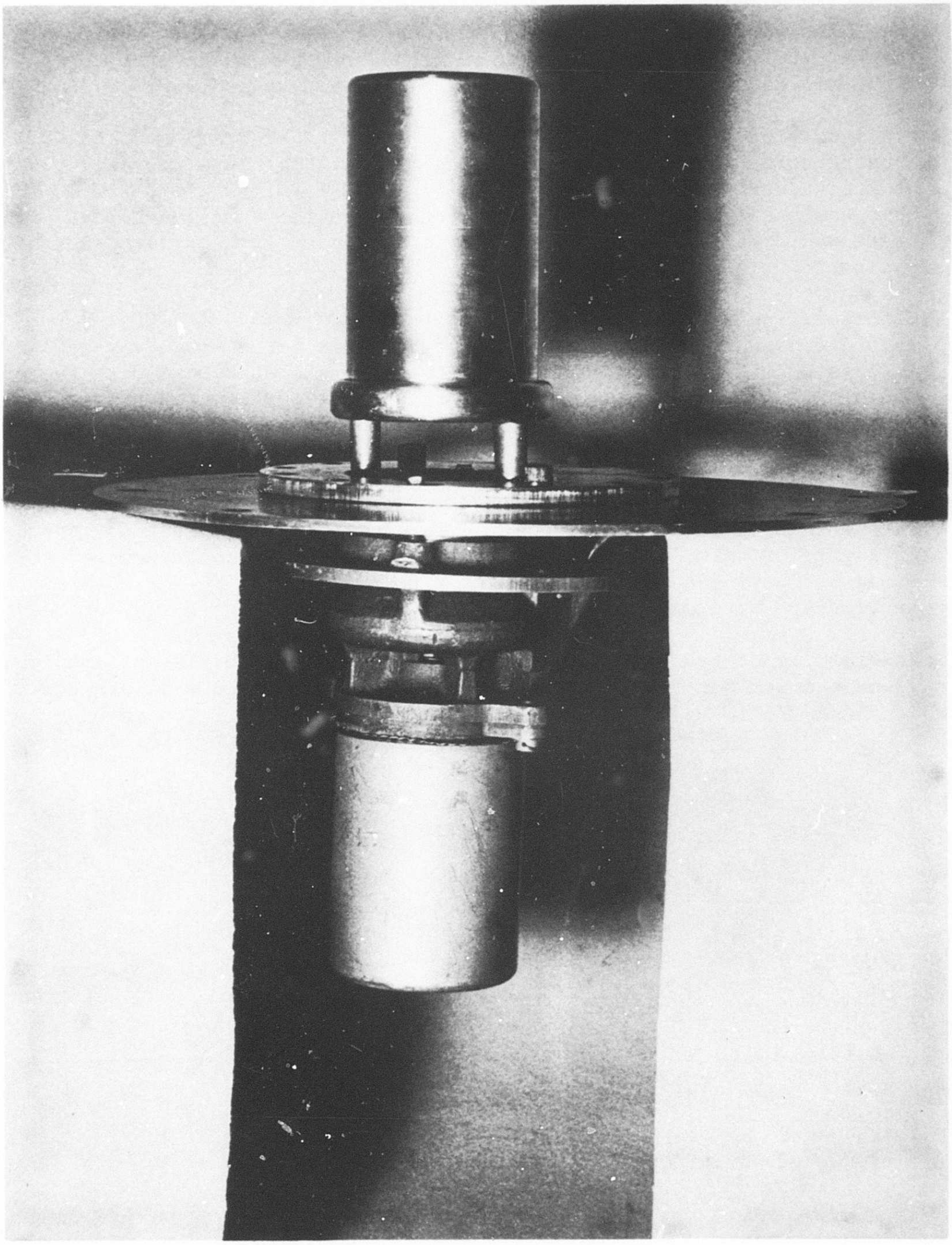

Figure 60. Outlet Configuration 5.

Configuration 2 as shown in Figure 57 consisted of a dummy pump motor and pump inlet corresponding to that of Boost Pump A except that the inlet was a full 360 degrees instead of 180 degrees. The brass adapter of Configuration 1 was used with the dummy pump motor. With this configuration, flow from the tank was by gravity.

Configuration 3 as shown in Figure 58 consisted of Boost Pump A mounted normally at the pump mounting flange. The pump was operated at its highest rate to withdraw emulsion from the test tank. This was considered to be the worst condition for emulsion removal since there would be little time for adhering emulsion to flow down the tank walls.

Configuration 4 consisted of the brass adapter fitted to Boost Pump A from which the bottom cover of the impeller chamber was removed. In this configuration, the normal intakes for Boost Pump A were sealed, and with the pump mounted in an inverted position,the pump was fed both by its own suction and by gravity. This configuration is shown in Figure 59.

Configuration 5 combined the inverted Boost Pump A and the adapter with the dummy pump with 360-degree inlet. This configuration, shown in Figure 60, simulated an immersible pump with the motor mounted as usual but having a 360-degree inlet with the pump being fed both by suction and by gravity.

The results of tests using Emulsion A with the five different configurations and various tank dimensions as indicated in Figure 61 are shown in Table IV.

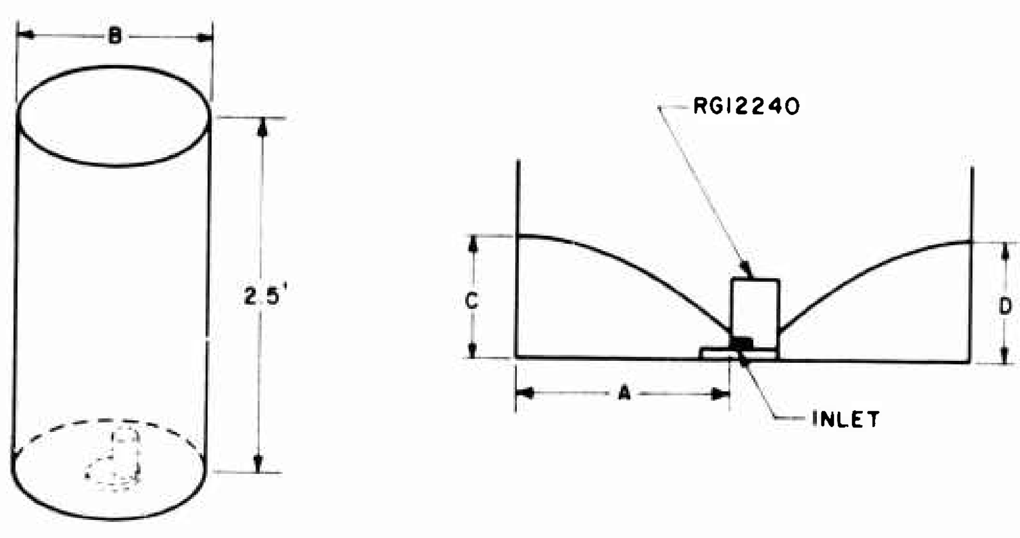

Figure 61. Test Tank Dimensions.

TABLE IV. TANK CONFIGURATION TEST RESULTS

Con-figuration	Dimensions in Inches A	B	C	D	Fuel Weight Full (pounds)	Fuel Weight Remaining (pounds)	Percent Fuel Remaining
1	3	9	1.5	1.5	50	4	8
1	4.5	12	1.75	1.75	90	5	5.5
1	7.5	18	2.0	2.0	205	13	6.4
1	10.5	24	2.75	2.75	365	32.5	8.9
1	13.5	30	3.5	3.5	573	64	11.2
2	3	9	4.75	4.75	50	8	16
2	4.5	12	5.5	5.5	90	17	18.9
2	7.5	18	6.0	6.0	205	42	20.5
2	10.5	24	6.5	6.5	365	77	21.1
2	13.5	30	6.5	6.5	573	120	20.9
3	3	9	1.5	3.0	50	7	14
3	4.5	12	2.0	2.75	90	10	11.1
3	7.5	18	2.25	3.0	205	22.5	11
3	10.5	24	2.375	3.25	365	37.5	10.3
3	13.5	30	3.5	3.75	573	81.3	14.2
4	3	9	2.25	2.25	50	5	10
4	4.5	12	2.25	2.25	90	7	7.8
4	7.5	18	3.0	3.0	205	19	9.3
4	10.5	24	6.5	6.5	365	80	21.9
5	3	9	1.5	1.5	50	4	8
5	4.5	12	1.75	1.75	90	8	8.9
5	7.5	18	3.5	3.5	205	24	11.7
5	10.5	24	3.75	3.75	365	45	12.3
5	13.5	30	5.0	5.0	573	98	17.1
5 (larger inlet)	10.5	24	2.75	2.75	365	32	8.8
4 (30° bottom)	10.5	24	8	8	365	72	19.7
3 (30° bottom)	10.5	24	2.5	-	365	9.5	2.6
5 (larger inlet & 30° bottom)	10.5	24	1.25	1.25	365	15	4.1

Comparison of Configurations 1 and 2 with both tanks drained by gravity shows that Configuration 1 gives better drainage. Configuration 2 restricts drainage despite the fact that the total inlet area around the 360-degree inlet equals the inlet area of Configuration 1. This indicates that pump inlet area for present pumps should be increased.

Comparison of Configurations 3 and 4 indicates that gravity feed combined with suction has advantages in the smaller tank sizes. At the larger tank size,the direct feed into the pump as in Configuration 4 allows the emulsion to be removed rapidly from the area directly above the pump,and air is drawn into the pump sooner, leaving more emulsion in the tank.

Configuration 3, which is the normal pump configuration, gives data which show optimum percentage removal of emulsion when the pump inlet is located 10.5 inches from the tank wall.

Configuration 5 is actually a combination of Configurations 2 and 4. By using a 360-degree inlet combined with gravity and suction feed, it was thought that the difficulty encountered in the larger tank sizes with Configuration 4 could be eliminated. A considerable improvement did occur in the larger tank sizes, but at the price of a slight loss in the smaller sizes. Increasing the area of the 360-degree dummy pump inlet produced a further improvement with the optimum inlet to wall distance test tank.

The effect of angling the bottom of the optimum cylindrical tank was checked using Configurations 3 and 4 with a 30-degree angled bottom. Configuration 4 showed only slight improvement since the volume directly above the inlet was quickly exhausted; but Configuration 3, the normal configuration, gave the best performance of any configuration-tank size combination. Use of Configuration 5 with the larger inlet area and the 30 degree angled bottom showed further improvement but was still not as good as Configuration 3 with the angled bottom. Tank height does not have as much, if any, effect on fuel removal as do the tank bottom configuration, the inlet to wall distance, and the pump inlet configuration.

Boost pumps currently in use will be satisfactory for use with emulsified JP-4 fuels of the type tested, and maximum fuel withdrawal can be obtained by using tankage lined with polytetrafluoroethylene or polyethlene with the tank bottom angled 30 degrees.

Some slight additional advantage might be gained by enlargement of the inlet area of present pumps, by increasing both the arc of the inlet and the inlet height.

FUELING TECHNIQUE

In a tank of adequate dimensions as outlined in the section on tank design, no difficulty was encountered in filling the tank when the test emulsions were introduced at the bottom. Under such circumstances, once the first fuel was in the tank and covered the inlet to a depth of 6 inches, the fuel level rose uniformly and there was no air entrapment. The angled-bottom tanks are better than flat-bottom tanks when bottom filling is used.

In filling the test tankage from the bottom, the fuel was directed vertically down toward the bottom and in other tests was directed upward from the bottom at a 45-degree angle. When the fuel is directed upward, the fueling rate must be decreased to prevent splashing of the fuel.

Fueling rates and line sizes must be controlled in any case, since high shear conditions will cause partial emulsion breakage. To obtain fueling rates equivalent to those used with JP-4, the fueling pump sizes and the fueling line diameters should be increased.

FUEL SYSTEM DESIGN

RETROFIT

While all of the boost pumps tested could handle Emulsions A and B at reduced efficiency under the test conditions, the pressure drops incurred by the fuel lines and the fuel filter indicate that Pumps A, B, and D will not develop sufficient flow in the fuel system. The fuel line data for polytetrafluoroethylene-lined tubes with 1.0-inch inside diameter show a pressure drop of approximately 1.1 psi for 1000-pph flow in a 32.5-inch-long section. The pressure drop across the filter alone is approximately 5.25 psi at the same flow rate. Only Pumps C and D develop sufficiently high pressure drops incurred. Since C is powered by a 400-Hz, 115-vac motor, it cannot be used in place of the 28-vdc pumps without modification to the aircraft electrical system. A larger dc motor-driven pump such as Pump E will be required to retrofit present dc pump aircraft. Provision should be made for controlling the speed of the boost pump according to flow demand in order to reduce emulsion breakage at low flow and to avoid the flow and pressure pulsations which result.

The fuel lines of the aircraft should be replaced by at least 1.0-inch-inside-diameter polytetrafluoroethylene or polycarbonate lined tubing. Alternately, lines made of these materials can be used. Fittings should be made of, or lined with, these materials, and lines depending on gravity flow should be lined and should have at least a 2.0-inch-inside diameter.

Present filter housings with enlarged tubing inlets and outlets for 1.0-inch ID tubing can be used with 115-micron, stainless steel, wire mesh filters. Filter bypass operation will have to be set to a higher value, probably 8 psi.

Present tank configurations are such that very little would be gained by lining them with polyethylene. The thickness of fuel adhering to the vertical walls of present liners is in the region of 1/4 inch and is very small in comparison to the material which will lie on the tank bottom and not flow to the pump. Lining of tankage for retrofit appears reasonable only if the tank bottoms are angled approximately 30 degrees for better pump feed and the pump inlet is no more than 10.5 inches away from the farthest tank wall.

Fuel quantity can be measured by using a capacitance gauge with an insulated probe such as the type tested. The unit which was tested would require modification as noted.

Fueling should be carried out from the bottom of the tanks either by using an integral tube to extend to the bottom or by using an extension on the fueling line. Fueling pumps will have to be larger in size for the same fueling capacity in order to reduce emulsion breakage from high shear.

NEW CONSTRUCTION

For future aircraft applications where emulsified JP-4 is to be used, the fuel boost system should have the following design features:

1. Aircraft tankage should be built up of pressurized compartments containing bellows or spring-reinforced bags. By manifolding the compartments and check-valving the pressurization inlet and fuel outlet for each compartment, isolation of individual units could be achieved in case of damage from ballistic causes or from crashes. Such tankage design would eliminate the need for boost pumps, and fuel feed would be possible for any flight attitude. Fuel retention would not be a problem in such tanks, and special tank linings would be unnecessary. Fuel boost pressure would be constant, and emulsion breakage during low flow would not occur.

2. Fuel lines and fittings should have at least a 1.0-inch inside diameter and should be internally coated with, or made of, polytetrafluoroethylene or polycarbonate.

3. Filtration to a 115-micron level with stainless steel wire mesh should be used to protect the engine-driven pump.

4. Provision should be made for filtration to a 20-micron maximum level between the engine-driven pump and the fuel control valve. Such filtration would require either a complete demulsification of the fuel or the use of an engine-driven pump which could develop sufficient pressure to force the fuel through the filter as well as supply the fuel pressure required by the engine.

5. Fuel level in each compartment could be measured potentiometrically by following the movement of the bellows or spring-reinforced bag.

6. Fueling should be carried out by using the same fuel lines leading to the engine for distribution of the fuel to the compartments in the tankage.

CONCLUSIONS

It is concluded that Emulsions A and B can be used in place of JP-4 fuel with fuel boost systems modified as noted in the section entitled Fuel Systems Design.

RECOMMENDATIONS

1. Work should be initiated to determine the filtration level required for operation of present engine driven pumps without damage or degradation of performance over periods of normal pump life.

2. A system should be devised for controlling the speed of present boost pumps as a function of engine fuel demand.

3. A method should be devised to allow filtration of the fuel to a maximum level of 20 microns.

4. The design of pressurized, compartmentalized fuel tanks should be investigated.

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13. ABSTRACT

The object of this program was to determine the design features and techniques which would permit the fuel system to deliver emulsified JP-4 fuel from the fuel tanks of United States Army aircraft to the engine in a dependable manner. The study was carried out in a series of experimental investigations covering emulsion behavior, fuel lines and fittings, fuel boost pumps fuel filtering and decontamination, fuel quantity measurement, fuel tank design, and fueling techniques. The studies indicated that current systems are usable providing that fuel lines are made of, or lined with, polytetrafluoroethylene or polycarbonate and that line inside diameters are not less than 1.0 inch. Fuel tanks should have bottoms which are angled 30 degrees, and the tank interior should be lined either with polytetrafluoroethylene or with polyethylene. Filtration of the emulsified fuel is limited to approximately 115 microns. Centrifugal fuel boost pumps perform with reduced efficiency, but some are usable. Inlets for the pumps should be modified to reduce fuel hang-up, and provision should be made to eliminate emulsion breakage by the pumps during periods of low flow demand. A capacitance gauge with insulated probe was found to be satisfactory for measurement of fuel quantity. Tank fueling operations will require low shear pumps, and the fuel should enter the tanks from the bottom.

The major limitations, for which further investigation is recommended, are the breakage of emulsion by the pumps during low flow demand, which leads to pressure and flow pulsations when higher flow demands are restored, and the limit of 115 microns for fuel filtration, which is felt to be five times too high.

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